GEOGRAPHICAL PAPER No. 50

Isodemographic Map of Canada

L. Skoda and J. C. Robertson

LANDS DIRECTORATE

Department of the Environment

Ottawa, Canada

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The contract for this project was initiated by the former Economic Geography Section, Department of Fisheries and Forestry. As a result of the government reorganization to create the new federal Department of the Environment, the Economic Geography Section was disbanded and most of its functions, including the responsibility for the Geographical Paper series, were transferred to the newly created Lands Directorate in the Lands, Forests and Wildlife Service of that department.

Editor, Sheilah V. Balchin
Department of Energy, Mines and Resources
Ottawa, Canada.

Errata

Page 4, line 24, column 1:

For: Such a method is simpleand straightforward, and is useful for diagrams which we composed of a small number of major units.

Read: Such a method is simple and straightforward, and is useful for diagrams which are composed of a small number of major units.

Page 14, line 9, column 1:

For: This process, illustrated in Figure 11, continued until all the gaps on the assembly board were filled.

Read: This process, illustred in Figure 13, continued until all the gaps on the assembly board were filled.

Page 14, line 5, column 2:

For: At the other extreme, the balls would occupy a minimum plan area if their tangents formed hexagons (see Fiture 13).

Read: At the other extreme, the balls would occupy a minimum plan area if their tangents formed hexagons (see Figure 14).

Page 16, line 6, Figure 14B:

For: Arrangement in which a ball theoretically "occupies" a minimum plan area, i.e., $\sqrt{12r^2}$

Read: Arrangement in which a ball theoretically "occupies" a minimum plan area, i.e., $r^2\sqrt{12}$.

Page 16, line 8, Figure 15B:

For: The "theoretical minimum" line represents the mean minimum of a theoretical set of units calculated to occupy minimum plan areas (as in Figure 13B) while forming a square as nearly as possible.

Read: The "theoretical minimum" line represents the mean minimum of a theoretical set of units calculated to occupy minimum plan areas (as in Figure 14B) while forming a square as nearly as possible.

Page 17, line 41, column 2:

For: In the case of the urban models, the mean difference between the expected and actual areas was found to be close to zero (see Figure 13): the models were very close to their anticipated scale of 4,480 people per square inch.

Read: In the case of the urban models, the mean difference between the expected and actual areas was found to be close to zero (see Figure 15): the models were very close to their anticipated scale of 4,480 people per square inch.

Page 30, line 2, column 1:

For: A tabular printout with numerical data output is illustrated in Figure 18, showing the first page of data for Census Metropolitan Area of Calgary.

Read: A tabular printout with numerical data output is illustrated in Figure 19, showing the first page of data for Census Metropolitan Area of Calgary.

Page 30, line 9, column 1:

For: Each run could also generate a complete listing of points defining each census unit (Figure 19).

Read: Each run could also generate a complete listing of points defining each census unit (Figure 20).

Page 30, line 6, column 2:

For: The first section produced a map of the whole region (or subregion) at a specified scale on Lambert conformal conic projection (Figure 20A).

Read: The first section produced a map of the whole region (or subregion) at a specified scale on Lambert conformal conic projection (Figure 21A).

Page 30, line 8, column 2:

For: The second section defined the constituent census units at a specified isodemographic scale (Figure 20B) printing these in numerical order in columns.

Read: The second section defined the constituent census units at a specified isodemographic scale (Figure 21B) printing these in numerical order in columns.

Page 34, line 25, column 2:

For: Simmons, J. and R. 1939: Urban Canada, The Copp-Clark Publishing Co., Toronto, 1969.

Read: Simmons, J. and R. 1969: Urban Canada, The Copp-Clark Publishing Co., Toronto, 1969.

Errata

Page 4, line 21, column 1:

For: Such a method is simple and straightforward, and is useful for diagrams which are composed of a small number of major unit.

Read: Such a method is simple and straightforward, and is useful for diagrams which are composed of a small number of major units.

Page 11, line 9, column 2:

For: This process, illustrated in Figure 11, continued until all the gaps on the assembly board were filled.

Read: This process, illustrated in Figure 15, continued until all the gaps on the assembly board were filled.

Page 14, line 5, column 2:

For: At the other extreme, the balls would occupy a maximum plan area if their tangents formed hexagons (see Figure 15).

Read: At the other extreme, the balls would occupy a minimum plan area if their tangents formed hexagons (see Figure 16).

Page 16, line 4, Figure 16:

For: Arrangement in which a ball theoretically "occupies" a minimum plan area, i.e., $r^2\sqrt{3}$.

Read: Arrangement in which a ball theoretically "occupies" a minimum plan area, i.e., $2r^2\sqrt{3}$.

Page 16, line 8, Figure 15b:

For: The "theoretical minimum" line represents the mean minimum of a theoretical set of units calculated to occupy minimum plan areas (as in Figure 15b) while forming a square as nearly as possible.

Read: The "theoretical minimum" line represents the mean minimum of a theoretical set of units calculated to occupy minimum plan areas (as in Figure 16) while forming a square as nearly as possible.

Page 17, line 41, column 2:

For: In the case of the urban models, the mean difference between the expected and actual areas was found to be close to zero (see Figure 17). The models were very close to their anticipated scale of 1,450 people per square inch.

Read: In the case of the urban models, the mean difference between the expected and actual areas was found to be close to zero (see Figure 15). The models were very close to their anticipated scale of 1,450 people per square inch.

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Page 30, line 8, column 1:

For: Each run scale plan generates a complete listing of points defining each census unit (Figure 20).

Read: Each run scale plan generates a complete listing of points defining each census unit (Figure 21).

Page 30, line 2, column 2:

For: The first section produced a map of the whole region for reference on a specified scale on Lambert conformal conic projection (Figure 22).

Read: The first section produced a map of the whole region for reference on a specified scale on Lambert conformal conic projection (Figure 22a).

Page 30, line 8, column 2:

For: The second section defines the constituent census units at a specified isodemographic scale (Figure 22b) printing them in numerical order in columns.

Read: The second section defines the constituent census units at a specified isodemographic scale (Figure 22b) printing them in numerical order in columns.

Page 54, line 11, column 2:

For: Simmons, J. and R. (1969) Urban Canada, The Copp Clark Publishing Co. Toronto, 1969

Read: Simmons, J. and R. (1969) Urban Canada, The Copp Clark Publishing Co., Toronto, 1969.

Preface

Maps have many uses. One of the most important is that of providing a visual impression of facts which would be difficult to communicate in any other way. The isodemographic maps described in this report are intended to provide accurate impressions of the regional distribution of the Canadian population, of the urban-rural ratio , and of the variation in population density within Canada's major cities, which would not be possible on the conventional map. The Isodemographic Map of Canada may be thought of as the map of Canadians; as such it differs from the map of Canada, the land areas where Canadians live.

Because it has only a general resemblance to the conventional map, the isodemographic map is of no use to someone wishing to find his way from one place to another. Nor is it a useful base on which to plot data which are related to the area of Canada, such as statistics on agriculture, resource development or transport. There are, however, many types of data which are directly related to people, including health, education, income and employment. If such data are to be shown in map form, as is frequently necessary, the isodemographic map is a much more suitable base than the conventional map.

Although many attempts have been made, these maps are believed to be the first in the world which show census divisions isodemographically in such detail. Their preparation involved the development of a technique which would achieve an accurate result at moderate cost within a short period of time. Messrs. Robertson and Skoda, and their enthusiastic assistants, achieved a solution which is intellectually satisfying and cartographically useful. The project is an excellent example of cooperation between the federal government and the university community, although the complexity of the task asked of the contractors was not fully appreciated by the federal representatives until they received the manuscript of this report.

R.J. McCormack,
Director,
Lands Directorate,
Lands, Forests and Wildlife Service,
Department of the Environment.

Préface

Les cartes ont de nombreux usages dont le plus important consiste à donner une impression visuelle de faits malaisés à communiquer autrement. Les cartes isodémographiques décrites dans le présent rapport visent à donner des impressions précises sur la répartition régionale de la population canadienne, sur le rapport entre la population urbaine et la population rurale et enfin sur les variations que connaît la densité démographique des principales agglomérations canadiennes, autant de renseignements qu'une carte classique ne pourrait donner. Bien que l'on se soit servi du terme "isodémographique" pour décrire ce genre de cartes, on peut quand même les considérer comme les cartes de la population canadienne; à ce titre la carte isodémographique diffère de la carte du Canada, qui représente les régions géographiques dans lesquelles vivent les Canadiens.

Du fait que la carte isodémographique ne présente qu'une ressemblance générale avec la carte classique, elle n'est d'aucune utilité à celui qui désire établir l'itinéraire à suivre pour se rendre d'un endroit à un autre. De même, il ne s'agit pas d'un élément utile pour inscrire des données relatives à la superficie du territoire canadien, comme des statistiques sur l'agriculture, sur la mise en valeur des ressources et sur les transports. Cependant, il existe bien des types de données ayant un rapport direct avec la population, dont la santé, l'enseignement, le revenu et l'emploi. Si l'on doit exprimer ces données sous forme cartographique, ce qui est souvent le cas, la carte isodémographique est une forme de carte beaucoup plus adaptée que ne l'est la carte classique.

Bien qu'elles aient déjà fait l'objet de nombreuses tentatives, ces cartes sont les premières au monde à montrer sous forme isodémographique et aussi détaillée les divisions techniques de recensement. La préparation de ces cartes a demandé l'élaboration d'une technique qui devrait sous peu, apporter des résultats exacts pour un coût raisonnable. M.M. Robertson et Skoda ainsi que leurs enthousiastes adjoints sont parvenus à une solution satisfaisante sur le plan intellectuel et utile sur le plan cartographique. Leurs travaux sont un excellent exemple de la collaboration entre l'administration fédérale et la communauté universitaire, bien que ce n'est qu'auprès réception d'une version manuscrite de ce rapport, que les autorités fédérales ont pleinement apprécié la complexité de la tâche demandée à ceux qui l'ont entreprise.

R.J. McCormack,
Directeur,
Direction des Terres,
Service des Terres, Forêts et de la Faune,
Ministère de l'Environnement.

Abstract

The extreme spatial contrasts in population density in Canada, partly due to the advanced stage of urbanization, make a conventional map an unsuitable base to use in the presentation and analysis of many population characteristics. A map of Canada has therefore been devised in which the areas occupied by census units are proportional to their population. In addition, separate maps of the twelve largest urban centres have been devised which show census tracts in the same manner but at a larger scale.

The necessary transformation of the area and shape of census units was achieved mechanically by means of physical models of Canada and the individual cities in which the populations of the units were represented by appropriate numbers of 1/8″ diameter steel ball bearings. The final output, termed an isodemographic map, is a graphical refinement of the physical models to which boundary detail and some topographic features have been added to aid the user. The isodemographic concept, the constraints and the method of construction are discussed and illustrated, together with some examples of possible uses of the map.

Résumé

Les disparités extrêmes que connaît la densité de la population du Canada, par rapport à l'espace d'occupation, disparités qui sont partiellement imputables au stade avancé de l'urbanisation, font que la carte traditionnelle n'est plus adaptée à la présentation et à l'analyse des multiples caractéristiques de la population canadienne. C'est pourquoi les auteurs ont établi une carte du Canada sur laquelle les zones qu'occupent les unités techniques de recensement sont proportionnelles à la population qu'elles renferment. En outre, des cartes distinctes des douze plus grandes conurbations ont aussi été établies, indiquant de la même manière mais à une échelle supérieure, les secteurs de recensement.

La modification qu'il a fallu apporter à la superficie et à la configuration des unités techniques de recensement a été effectuée mécaniquement au moyen de modèles matériels du pays et, de billes métalliques de 1/8^{e} de pouce, pour ce qui est des villes particulières dont la population des unités de recensement a été indiquée.

La carte isodémographique est le résultat final du report graphique des modèles matériels auxquels ont été ajoutés des détails de frontière ainsi que certaines caractéristiques topographiques utiles. En plus de certains exemples de diverses utilisations possibles de la carte, on trouvera un exposé et une illustration du principe isodémographique, des contraintes qu'il comporte et de la méthode de fabrication.

Acknowledgments

The authors wish to express their gratitude to the following: Dr. C.I. Jackson, former Head of the Economic Geography Section, Department of Fisheries and Forestry, for his guidance, advice and final editing of the manuscript; J.W. Maxwell, formerly a research officer in the Economic Geography Section, for his valuable support; Mrs. V. Cranmer for checking the map output for acceptance by the Government; A.W. Meindhardt for his valuable contribution as a permanent research assistant; Stan Thomson for building most of the urban models; summer assistants Morris Jacobson, Larry Foster, Marilyn Marshall, Lise Ouimet, Sue Du Bois; Roger Toren, who prepared the computer programs for the early phases of the work; Hugh McFadden, Neil Burke, Sid Witiuk, Des Lundy, John Hunt, Gerhard Brenner, and Bill Archibald who helped out on occasion; R.B. Sagar, Chairman, Geography Department, Simon Fraser University, for permission to use Departmental equipment and resources; and Dr. H. Peter Oberlander, Director, School of Community and Regional Planning, University of British Columbia, under whose auspices the project was carried out.

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ISODEMOGRAPHIC MAP OF CANADA

L. Skoda and J.C. Robertson***

Introduction

Canada is at present in an advanced stage of urbanization. At the 1966 census, almost half its people lived in only twenty-three urban areas each with a population over 100,000.[1] The three largest centres, Montreal, Toronto and Vancouver, accounted for more than a quarter of the total, with one in every eight Canadians living in Greater Montreal. The scale and significance of this urban character of Canada have been analyzed and documented in many ways.[2] Yet, some essential characteristics of urbanization, especially those which are directly related to the people themselves (rather than the area which they occupy), are difficult to present graphically and remain a major challenge to cartographers.

Maps are a frequent and an indispensable way of communicating information which involves a distribution in space. The word 'Canada' may, to some people, suggest the flag or some other national symbol; to most, it probably immediately calls up a mental image of a map of Canada. Such a map is, however, a map of the land area and its associated water bodies: it is not a map of Canadians so much as a representation of where Canadians live. Conventional cartographic techniques do not adequately represent the urban characteristics which are the dominant component of the present social organization in Canada. On a small-scale conventional map, urban centres, plotted to scale, appear as minute areas. This lack of space is usually supplemented by ways in which individual data relating to them are symbolically represented by dots, squares and circles. Such representation normally leaves much to be desired if only because it usually fails to represent the data in a way in which the user has a correct perception of the relative size of urban units and of the urban-rural ratio.[3]

One example of the difficulty of providing a true perception of the urban character of the population is the oft-quoted statement that 90 per cent of the population of Canada lives within 200 miles of the U.S border. This is true, and conventional maps show it to be true, but in reality it adds little to our perception of the urban character of that population distribution: the conventional small-scale map tends to support the image of a continuous strip of population, whereas, in fact, a better generalization is that within that immense strip (approximately 300,000 square miles) the vast majority of the population lives in a few dozen large centres which exist in an enormous matrix of sparsely populated rural areas.

Conventional maps, by their very nature, are analog models of the earth's surface; their primary measure relates to land, and their areas are a function of physical distance, scale and projection. These, however, are the very characteristics which preclude a conventional map from communicating with equal effectiveness (on a single base with uniform scale) the social and economic variations that take place across a population whose distribution is not evenly spread across the land area. In the same way that conventional maps are drawn on projections which minimize distortions of physical characteristics (e.g. equal-area or orthomorphic projections), so an accurate map of population characteristics should be drawn on a base which will cause these

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characteristics to have a visual impact which is directly related to the size of the population, irrespective of that population's territorial extent.

The idea of a cartogram[4] in which the areas of the component units are proportional to some numerical values, such as their populations, is not new to cartography, and some forms of the idea can be traced to the middle of the last century.[5] Since that time, the technique of quantitative cartograms has been used to communicate social and economic as well as demographic data. Contributions in this field by the Woytinskys, Grotewolds, Buchanan, Hughes and Savage are discussed by Hunter and Young.[6] Other contributions by Harris, Hoover, Weigert, Getis and Zimmerman are described by Tobler.[7] To this list may be added a population cartogram *United States in Proportion to Population July 1, 1967* by the Ohio Bureau of Employment Services,[8] a cartogram *A Solid Waste View of the United States* by Albert J. Klee[9] and an excellent population map of the world designed by Mei-Ling Hsu as part of her cartographic contribution to the textbook *A Geography of Mankind* published in 1968.[10] In the same year, Hunter and Young published a demographic base of the countries of England and Wales. Their method of construction was a novel mechanical process in which wooden blocks were used as building units (Hunter and Young, 1968). The present authors are also aware that a mathematical technique utilizing computers in the transformation process is being developed by Tobler to produce a detailed demographic cartogram of the United States.

Two previous attempts to provide such a cartogram of Canada are known to the present authors. These are the highly generalized cartograms shown in Figure 1. One is a discontinuous presentation of the Federal Electoral Districts[11] in which the Electoral Districts are assumed, for convenience in construction, to have equal populations and were thus assigned equal map-areas.* This cartogram was prepared as a test of the potential usefulness of the present project and was patterned on a map of parliamentary constituencies published in the Reader's Digest *Complete Atlas of the British Isles.*[12] The second diagram appeared as a frontispiece in *Urban Canada*[13] by James and Robert Simmons and shows the metropolitan, urban and rural segments of population in each province. It should also be noted that a discussion on the merits of "... a base map in the form of a cartogram in which the county sizes were proportional to their populations" was recorded by Castner in his attempt to produce a base map for a new atlas of Ontario in 1968.[14] While recognizing the potential advantage of such a map, Castner rejected its use for his project because of his concern for preserving the familiar shape of Ontario.

The purpose of the following report is to describe the development of a relatively detailed map of this kind for Canada and for its major cities and to illustrate some of their possible applications. The term isodemographic, meaning 'equal population,' is used to describe these maps; the concept is discussed in more detail in Chapter IV.

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* The allocation of seats in the House of Commons is revised after each decennial census, with equal population the main criterion. There are other criteria, however, which in particular lead to representation of Prince Edward Island (4 seats), the Yukon Territory (1 seat) and the Northwest Territories (1 seat) which is well above the representation these areas would enjoy on a strict application of the equal population principle. Parliamentary seats are therefore only an approximation to the population distribution. Their boundaries also rarely coincide with census or other divisions and their usefulness as a basis for mapping is small. The rules governing the allocation of seats in the Commons are contained in the Electoral Boundaries Readjustment Act, Chapter E-2, Vol. III, Revised Statutes of Canada, 1970.

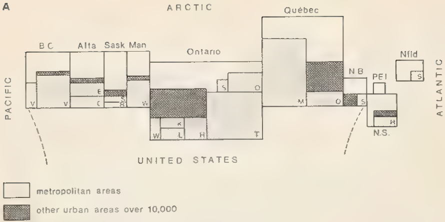
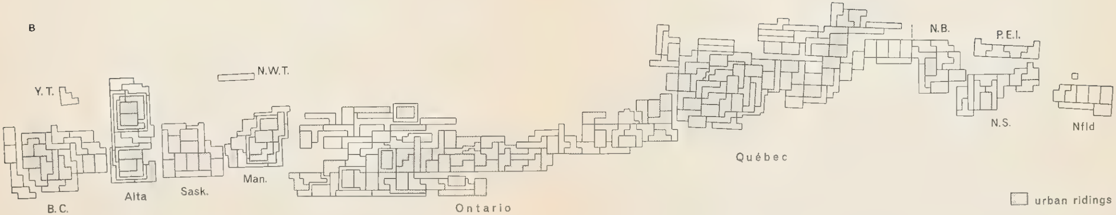


FIGURE 1. Recent demographic cartograms of Canada:

A – a diagrammatic presentation of three classes of population in each province. (Adapted from: James and Robert Simmons *Urban Canada*, The Copp Clark Publishing Company, 1969, frontispiece, p. viii.)

B – rectangular cartogram in which Federal Electoral Districts were used as mapping units. The districts were assumed to have equal population to simplify construction. The provinces appear separate but intraprovincial contiguity is maintained. (This cartogram was prepared by C.I. Jackson in 1969 and is reproduced here with his permission.)



Problems and constraints

The basic requirement

The basic task given to the authors was to construct a map of Canada in which the component units of population occupied areas proportional to their population. Basic units specified for this purpose were census divisions as defined by the 1966 Census of Canada.

Further requirements specified in the research contract were:

(a) The shape and the space relationships of the isodemographic map should, as far as possible, approximate objective reality.
(b) The geographical contiguity of adjacent census divisions should be preserved.
(c) The approximate boundaries of Census Metropolitan Areas and Census Major Urban Areas be shown for those centres with 1966 populations over 100,000.
(d) The position of meridians of longitude and parallels of latitude as well as selected topographical features be included to aid the map user.
(e) Twelve urban areas with populations greater than 200,000 be mapped separately in sufficient detail to show census tract boundaries.* The relevant shape and contiguity constraints be applied to these maps on an individual basis.

In general terms, the principal task involved a transformation of the geographic definition of the land area of Canada into a map representing its population. Although the research broke largely unfamiliar ground in catography, it was undertaken within definite time and financial constraints and these constraints were paramount in the choice between a number of conceptual and methodological solutions to the problem.

* The smallest urban area, Halifax-Dartmouth, had a population of 198,193 at the 1966 census.

Methodological problems and alternatives

The process of assigning map-areas to contig[illegible] geographic units according to their populations is a[illegible] exercise in the construction of what Erwin Raisz [illegible] "value-by-area cartograms" (Raisz, 1934). Althoug[illegible] process is basically a transformation of one aspect of geographical reality into an analog, it could also be viewed as a transformation of one map into another: a map in which component units represent land areas becomes one in which such units represent people.

In Tobler's view some transformations of quantitative cartograms can be adequately achieved by applying concepts from the theory of map projections. Cartograms that are not, however, amenable to this kind of treatment include those for which initial data are

> . . .in the form of discrete locations, as on a population dot map; or are grouped into areal units such as census tracts; or refer to areal units rather than to infinitesimal locations,. . . (Tobler, 1963).

For such cartograms, Tobler suggests, the functional equations are difficult to obtain although theoretically possible. The crux of the problem in the present context is the fact the transformation input requires the simultaneous consideration of three independent variables: areas of the units, contiguity, and the final shape of the external boundary of the cartogram (i.e. resemblance to the conventional map of Canada). If this last constraint were dropped, an infinite number of solutions would be possible. Only a very few of these, however, would be visually acceptable and cartographically useful. The dilemma is that the external boundary shape is required as an input for transformation but can only become precisely defined as an output.*

* This problem, of course, only arises in practical terms in a wholly analytical approach, such as is being taken by Tobler; it can be bypassed in empirical techniques using graphic and mechanical methods of transformation.

Possible methodological approaches to such transformation can be grouped into three general categories:

1. graphic
2. mechanical
3. mathematical

The categories are not in fact mutually exclusive; each one, to some extent, involves mathematical manipulations. Nevertheless they serve as useful headings and emphasize the principal method through which the transformation is achieved.

1. The graphic process is synonymous with traditional cartographic procedure requiring the simplest of drawing instruments and a good measure of cartographic judgment. A method described by Raisz[15] involves a two-phase procedure. In the first phase highly generalized major units, such as states or provinces, are drawn to a correct demographic scale on individual pieces of paper. Contiguous units are then adjusted to each other jigsaw fashion by successive approximations until gaps have been eliminated and the units form an acceptable general shape. In the second phase these major units are partitioned into suitable subunits. In the process of accretion, successive units are redrawn by hand.

Such a method is simple and straightforward, and is useful for diagrams which we composed of a small number of major units. However, Canada contains 241 census divisions (see Figure 2) and, in a project of such magnitude, the process of successive adjustments would represent an enormous manual repetitive task even to satisfy the requirements of correct area and contiguity. The third basic requirement – a desirable approximation to the actual land shape – can only be achieved by readjustments of the whole assembly. Each readjustment would probably require an effort equal in magnitude to the initial accretion stage.

2. In a mechanical approach the repetitive drawing stage is replaced by the construction of a physical analog model. Such a model becomes a link between the input data and the final map. The only known work of major proportions utilizing this method was reported by Hunter and Young (1968). In this project, 9,214 wooden blocks were used to construct a model of the population of the 62 counties of England and Wales. This approach offers substantial economy in effort over graphical techniques. A predetermined number of blocks are assigned to each mapping unit (e.g. to a county). During the model building, these units can be rapidly reshaped by relocating some of their blocks. However, the resolution of detail that can be achieved with the model depends mainly on the size of the blocks. The present project, including the individual city maps, comprises some 1,700 units in which relatively high detail resolution is required. Like the graphical approach, therefore, the use of wooden blocks would present problems because of the amount of handling required.

3. Mathematical methods utilizing computers are another means of resolving such cartographical problems. The process of transformation can be carried out entirely within the computer according to strict parameters, and following precise steps, as defined by a predetermined program. Such a technique is only feasible if there is a precise functional relationship between the independent variables of the input and the dependent variables of the output. As previously indi-

A

Province/Territory	Number of census divisions	CMA's or CMUA's
Newfoundland	10	1
Prince Edward Island	3	1
Nova Scotia	18	2
New Brunswick	15	2
Quebec	74	4
Ontario	54	8
Manitoba	20	1
Saskatchewan	18	2
Alberta	15	2
British Columbia	10	2
Yukon	1	0
Northwest Territories	3	0
Total	241	25
Total units for main map	266	

B

CMA	Number of tracts
Calgary	54
Edmonton	63
Halifax	24
Hamilton	71
London	42
Montreal	391
Ottawa	75
Quebec	54
Toronto	360
Vancouver	131
Windsor	45
Winnipeg	98
Total	1408

FIGURE 2. Project mapping units: A – main map, B – urban maps.

cated, the present problem falls into a class that does not readily lend itself to precise functional definition. This stems from the fact that in a fully analytical procedure the parameters for the shape of the external boundary of the cartogram must first be specified. Yet this can not be done since the shape of the external boundary should be a solution yielded by the functional equation. A partial analytical approach would be possible if the limits of an acceptable boundary shape could be specified.* At the time the Isodemographic Map of Canada was conceived a mathematical technique was being developed for a similar problem by Tobler. Adaptation of Tobler's methodology in the present project did not seem feasible, since the computer program was not expected to be available before the desired completion date of the Canadian project.

In the absence of such previous work in this field, the indications were that the development of a satisfactory computer program would be a task of such magnitude that the present authors were reluctant to undertake it if a suitable alternative method could be found. The value of computers in such work is, of course, not in dispute. Too often, however, it is the computer's execution time that is quoted as its main advantage. The time-consuming preparations required to create, produce and test a sound program necessary to establish a strict regime under which the computer can carry out its simple "counting" procedures are often overlooked.

It seemed, therefore, that within the restrictions of time and financial resources available, some form of mechanical approach would prove the most rewarding. A material was required capable of holding an assigned area and shape as well as being amenable to reshaping without changing its assigned area. Other prerequisites were that the substance could be easily measured and contained. In the final search, steel ball bearings offered the best solution. Balls of 1/8″ diameter were selected for building the analog models. The required number of balls representing the population of each unit were weighed or counted and then contained in a fence arrangement of metal strips representing a generalized form of the boundaries of the mapping units. The ball "matrix" could readily accommodate between-unit adjustment and allow reshaping of the model in aggregate. In addition, the cost of the balls was modest: in their final form, as used in industry, the balls cost approximately $4.00 per 1000; before final polishing they cost only $0.40 per 1000 and the specifications (i.e. the variation in diameter) were well within acceptable limits for the present purpose.

* This has major implications for the future development of the present project.

The methodological concept

Whatever approach is adopted – graphic, mechanical or mathematical – the transformation of the [illegible] units can be viewed as a three-stage problem:

(1) transformation of each geographic unit into its isodemographic equivalent;
(2) accretion of the resultant isodemographic units into contiguous formations; and
(3) shape adjustment of the whole assem[illegible] achieve a reasonable visual approximation t[illegible] actual land shape.

The problem could thus be viewed as an open [illegible] (Figure 3) in which the input consists of numerical [illegible] geographic definitions of census units and the outpu[illegible] the isodemographic map. The inner system fee[illegible] contains the necessary controls under which the [illegible] goals are achieved. These controls are discussed later

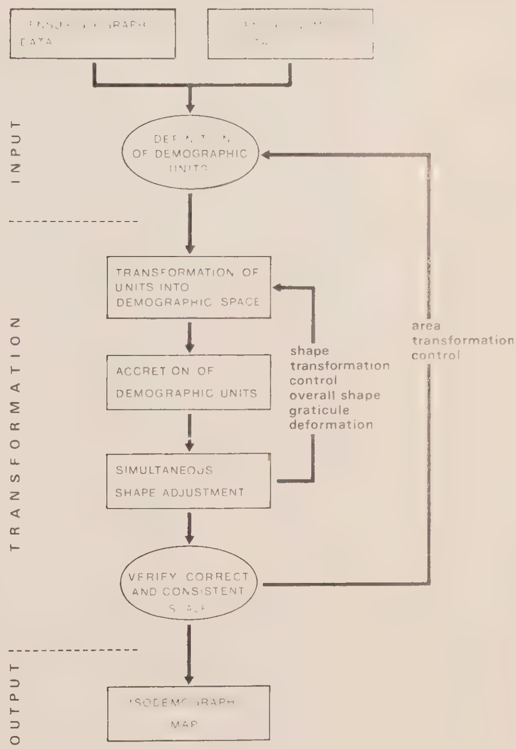


FIGURE 3. The problem as a system: key elements and process.

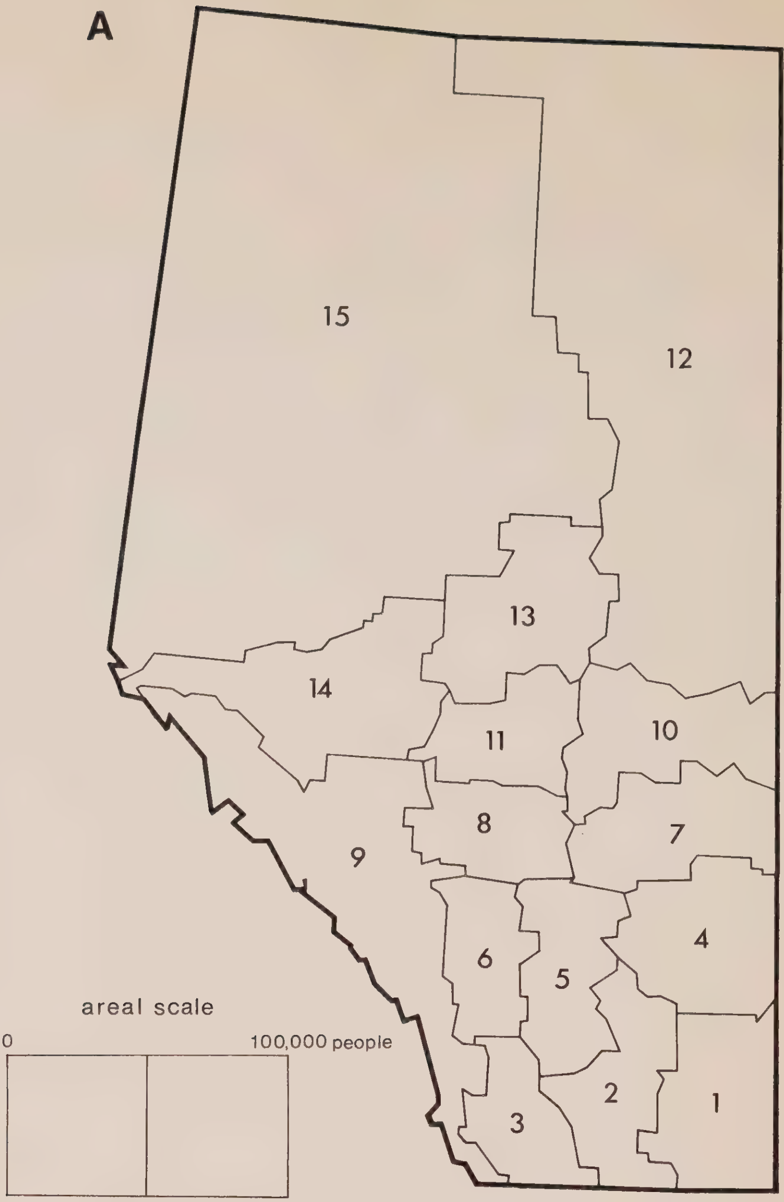


FIGURE 4. Isomorphic mapping units: aid to transformation.

A – Conventional map of Alberta on conformal conic projection showing census divisions. Alberta in this case is regarded as an isomorphic mapping unit with a demographic areal scale of approximately 70,000 people per square inch. This scale also becomes the mean demographic areal scale of the component census divisions although the divisions remain proportional to their land areas.

B – An arrangement of the individual census divisions with map-areas proportional to their population. The divisions retain their shape but are either reduced or enlarged relative to their sizes in A. The total area of the divisions is the same as the map-area in A. Dashed lines connect identical points on the boundary of neighbouring units. The shaded areas between the fine dashed lines indicate corresponding boundary segments which now have assumed differing lengths. To reassemble these units into a continuous representation of Alberta, their shape must be altered. Methods of altering the shape are discussed in the text.

B

Orthomorphic transformation

The initial step of the first stage transformation of census units from geographic to their isodemographic equivalents is a simple change of scale for an orthomorphic transformation of one unit. The population of a unit divided by a desired areal scale of x people per square inch specifies the 'isodemographic' size of the unit in map square inches. The initial unit is then enlarged or reduced without change of shape to produce this required map-area.

Figure 4B shows the census divisions of Alberta drawn to a common isodemographic scale. A land-based map in Figure 4A contains the same paper area within its perimeter: the aggregate area of the census divisions in Figure 4B. The individual census units in Figure 4B have merely undergone an orthomorphic transformation, i.e. a simple change of scale. The diagram shows both the result of this first stage and the more difficult task required in the second step: that of reshaping these units to form a continuous formation representing Alberta.

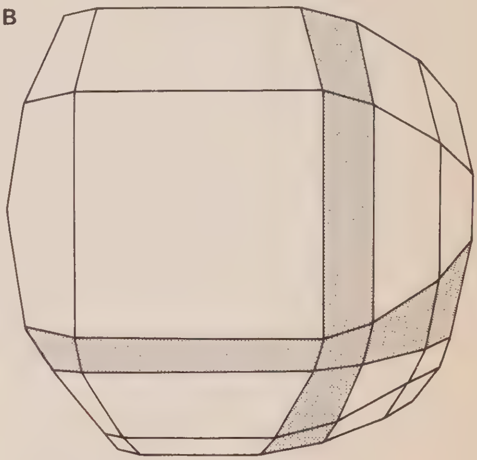
When steel balls are used in the transformation, it is necessary to reverse these two steps: establish contiguity of the units and then ensure that the units occupy the correct area. This order is dictated by the fact that the containing fences must be established before the balls are added to the model. There are two ways in which the fence boundaries can be established. One is to construct census boundaries of the map at a demographic scale equal to the mean demographic scale of its constituent census units such as shown in Figure 4A. The predetermined number of balls placed in each unit will then determine which units are to expand at the expense of others. In the second method boundaries are constructed over an assembly of orthomorphic units such as illustrated in Figure 4B. In this case all units, to begin with, are too large and need to be collapsed until each attains a correct area. In the first case pressure is applied to the balls from above so that they spread laterally; in the second case the collapsing of the units is achieved by forcing the peripheral boundaries toward the centre of the assembly. In either case, both the contiguity and the areal requirements are attained through the "fluidity" of the balls and the telescoping and collapse of the boundary fences. These two properties of the model in combination also enable the reshaping of the whole assembly since the consitutent units can form mutually adjusting and continuous formations, thus satisfying the third part of the transformation problem.

A

10	70	15	16	7
48	225	44	41	12
5	19	6	12	7
5	46	10	8	3
1	8	4	4	2

A — a square matrix with numerical values equal to a hypothetical population in each cell.

B



B — transformed matrix with individual cells assuming areas proportional to their numerical value. Restrictions to this sample transformation were: the cells maintain their correct contiguity, grid line direction may not change at any point by more than 15° either way and a minimum dimension of any unit must be .1″. In this case the shape of the largest unit was retained, although other solutions were possible. In any solution, the transformation deforms the grid lines into "curves" concave toward the highest value, i.e. the largest unit.

FIGURE 5. Shape deformation principle: a hypothetical situation in which map grid lines designate segments of territory with different populations.

Overall control

Although the final shape of the cartogram could not be predicted as a specific case, a general objective could be formulated and aimed for during construction. The task here was to select appropriate parameters for guidance on how the units should adjust to achieve a desirable result. A simple but effective solution was found by accepting the graticule of meridians and parallels as a primary reference system, and in particular by attempting to retain the regularity of specific meridians and parallels important in Canadian political geography.

The regularity of the conventional graticule could be expected to be deformed in a systematic manner which is predictable in outline if not in detail. The densely populated urban areas undergo relative expansion in the transformation from their land area to their isodemographic equivalents while the sparsely populated rural areas tend to contract. The graticule lines would thus become widely spaced near urban environments and compacted over rural units, with individual lines becoming concave toward high population density points and convex toward sparsely populated areas. This concept provided the main clue to the shape transformation and is illustrated in Figure 5. Superficially the deformation suggests a grid deformation, as on Hägerstrand's logarithmic map (Hägerstrand, 1957). In this case, Hägerstrand's study was in migration, so that his primary concern was with a nodal region and therefore with distance rather than area. The nodality concept itself, although relevant, is of limited value for this project since the population cartogram under consideration is a poly-nodal region with each urban centre representing a node. Other aspects of this and similar projections have been analyzed by Tobler (Tobler, 1963) and need not be discussed further here.

Because the transformation problem was achieved in this project through the analog model, it was not necessary to quantify the graticule deformation beforehand.*

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* It is recognized that such quantification may, in itself, prove to be a partial mathematical solution to the problem. In this case, in summary, the final approach became an empirical one, with assistance by computer envisaged to provide routine calculations and orthomorphic printouts in the initial stages.

Development of the map

The basic concept which justified the use of the physical analog model was that the steel balls would enable the area of each census unit to be kept constant while the perimeter, and therefore the shape, of the unit could be continuously adjusted. The construction of this physical model was the main activity of the project, both in terms of its importance and as measured by the man-hours which it required. In the course of its construction the primary input data were transformed into an isodemographic representation of reality. In its completed form it was a model in an abstract as well as a physical sense: it was the basis on which details were added graphically to produce the final map. The project activities thus fell into three distinct phases in relation to the model: (1) preparation, (2) model building and (3) terminal activities.

Preparatory stage

The preparatory stage consisted of the quantification of the cartographic definitions of census boundaries and the manipulation of census numerical data. The Dominion Bureau of Statistics reports on the *1966 Census of Canada*[16] provided the primary sources for population data and for cartographic definitions of census units. Supplementary sources included maps of the National Topographic Series at scales of 1:25,000 and 1:50,000, which were used to supply detailed definitions of census boundaries in urban areas, and maps at 1:250,000 which were used in the same way in densely populated rural areas of Ontario and Quebec. A map of Canada at a scale of 1:2 million showing 1966 census divisions[17] provided the framework for point definitions of boundaries.

To aid in the initial stages of model building, orthomorphic transformation of census units to their isodemographic scale was produced with the aid of a computer as a line output on a "Calcomp" plotter. This step required that the boundaries be generalized into straight line segments and the points defining the boundary be identified by their geographical coordinates. The coordinates of each point were read out manually with the aid of a romer, recorded on a computer coding sheet and subsequently punched with numeric identification one point per card (see Figure 6). This information was stored on a magnetic disc and served as the primary object data in subsequent calculations of map projections, land areas of units, ratios and so on. This data, the computer steps and its applications are discussed in the Appendix. The computer output of the orthomorphic version of the demographic units was fully prepared only for the Prairie Provinces and for the individual cities of Edmonton, Calgary and Winnipeg. It served the useful purpose of aiding in the conceptualization of the shape transformation process during the initial period of model building. The exercise also provided some useful clues to procedures required and pinpointed difficulties likely to be encountered.

The generalization of census boundaries was carried out in two stages. In the first stage, boundaries were approximated by segments of straight lines retaining detail appropriate to final publication scale. The second stage further generalized these boundary lines into elementary shapes suitable for the model building. The 1/8″ diameter balls determined a lower limit to the degree of generalization. The model units thus provided the essential quantitative control and basic shapes. Detail was restored to approximately the first stage of generalization by graphical methods in the terminal operations. This process is illustrated in Figure 7.

Numerical input consisted of population counts for each census unit. From the population figures and the demographic map-area in square inches, the number of balls and the total weight of balls for each unit were calculated by a simple program using the following formulae:

$$\frac{\text{population}}{\text{demographic map scale}} = \begin{array}{l}\text{map-area in}\\ \text{square inches}\end{array} \qquad (1)$$

$$(1) \times 64 = \text{number of balls} \qquad (2)$$

$$(2) \times .1309 = \text{total weight of balls in grams} \qquad (3)$$

The demographic scale for the model of the main map of Canada was chosen as 8,960 persons per square inch (140 persons per ball).* The scale for the urban models was twice that, i.e. 4,480 persons per square inch (or 70 persons per ball).

Model building stage

The total number of balls required for the main model and the models of the twelve cities was 265,000. Preparing the required number of balls for each census unit could be done by counting although weighing normally proved to be less time consuming and equally accurate. The average weight of .1309 gm per ball was obtained by random sampling. A bench balance with 100 gm capacity could provide this accuracy and was used to weigh batches to the accuracy of one ball. As Figure 8 shows, sample checks indicated that the errors from weighing are small. Larger units would have required multiple weighings, resulting in loss of accuracy, and counting proved to be more expedient. Weighed and counted batches of balls for each census unit were stored in appropriately labelled plastic bags.

Metal strips to contain the balls and to represent the unit boundaries were cut in strips .10″ wide from .012″ gauge aluminum and .004″ gauge brass. The heavier aluminum strips were used primarily for the model of Canada with its relatively large census units while the more flexible brass strips were better suited for the urban tracts where the individual units were smaller.

The metal strips were hinged together with a mylar base adhesive tape. Two-, three-, four-, and five-arm hinges with varying arm lengths for each type of census unit junction were produced (Figure 9). Simple u-shaped glides were manufactured from the brass strips. The purpose of these was to slide over two overlapping hinge arms to preclude their drifting apart as the shape of the model was manually altered.

A board on which the main model could be assembled was constructed from 8′ x 6′ x 1-1/2″ plywood surfaced with white "Formica." This provided a hard, level and smooth surface on which the balls could move easily. The surface could also be drawn on,

* It might at first sight appear necessary only to define a scale for the model in terms of persons per ball. This is not the case because, as previously discussed, the balls do not necessarily fit together so that equal numbers of balls occupy the same area. Since the final output is a map, it is necessary to define the true scale in terms of population per square inch; population per ball is only a close working approximation to this and requires amendments at the terminal stage.

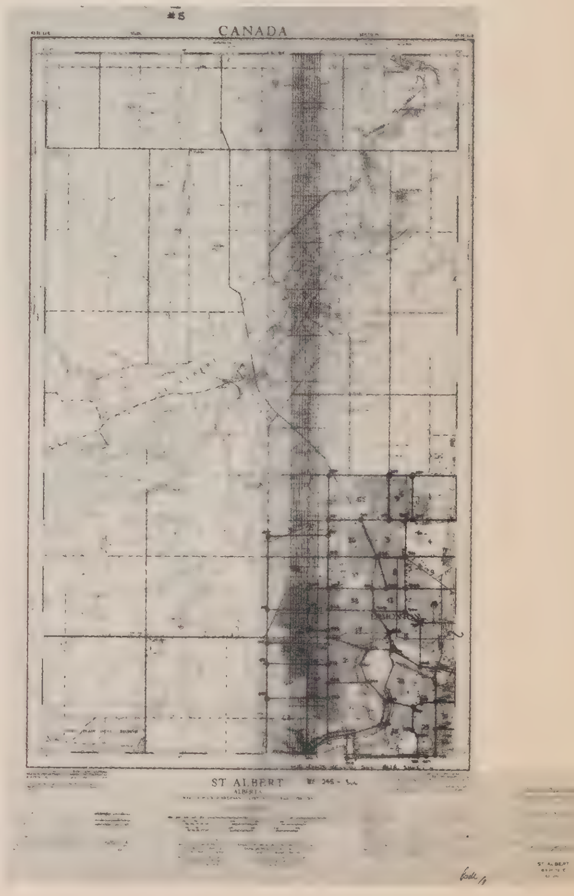

FIGURE 6. Readout of geographic coordinates: 1:50,000 topographic map-sheet 83H/12E, Alberta with romer in position. The heavy black lines represent generalized census tract boundaries in northwest Edmonton. The generalized boundary segments are identified by numbered points. Their geographic coordinates were read by registering the transparent romer scale to the map graticule divisions. On this map scale, the romer graduations allowed for direct reading to 6 seconds of arc and estimation to within 2 seconds. Coordinates of each point were recorded in degrees, minutes and seconds together with its number and an area code. The latter two gave each point a unique designation in computer storage.

FIGURE 7. Three levels of generalization:
A – East-west segment of a boundary between Divisions 10 and 7 in eastern Alberta as it appears on 1:2 million map of Prairie Provincess (MCR27),
B – first generalization; boundary in A generalized appropriate to proposed publication scale,
C – second generalization; boundary generalized into a straight line in model building,
D – third generalization; the same boundary as it appears on final graphics with appropriate detail from B reinstated.
The dashed lines in B and D represent the model boundary relative to the boundary detail. The change from curved line on B to a straight line on D (and C) was caused by deformation in transforming the census units from geographic to their demographic equivalents. The dashed line in B represents a line of best fit to the boundary detail with segments on either side of the line having the same area. The detail in D was reinstated following the same principle but is deformed due to the transformation.

which helped in planning and layouts. The board was fitted with 1/4″ raised edge to contain accidental spilling of balls. The twelve urban models were built on smaller individual boards.

In the early stages, construction of boundaries was aided by orthomorphic printouts of census units developed as described previously; boundaries of a cluster of contiguous units were built covering areas larger than required (see Figure 10). These were compacted to the correct areas after the balls were added. In later construction, as the model-building process became familiar, units were often added one at a time filled with the appropriate number of balls and continuously adjusted to direct the manner of deformation.

In building a unit, the appropriate type of hinge was selected for each vertex as defined by its generalized outline. Each hinge arm overlapped with the arm of the hinge at the next corner and the overlapping strip was secured by a glide to stop them drifting apart. The overlapping allowed for subsequent changes in shape and perimeter of the units.

Construction began with the Prairie Provinces, the first units built being those in southern Saskatchewan (see Figure 10). Census divisions in Saskatchewan are basically a simple arrangement of rectangular shapes and the preliminary transformation into their demographic equivalents could be readily visualized and the overall shaping easily controlled. Because of this advantage a substantial effort could be directed toward refining the model hardware and building procedures. To this extent the Prairie Provinces served as a "pilot" project.

Census divisions formed the principal units of the model and hence were assumed to have an even population density within their borders. During the construction and adjustment of the model boundaries the builders endeavoured to ensure that the graticule lines of latitude and longitude were not subjected to abrupt changes in direction. This constraint was difficult in areas of very steep population density gradients such as exist around Winnipeg and Montreal. Rural census divisions had to be "stretched" around these relatively enlarged urban areas if the requirement of contiguity was to be satisfied. This, of course, resulted in considerable deformation of the shape of the rural units. Although first priority was given to maintaining reasonable shape for divisions containing large urban centres, the extreme stretching necessary for the surrounding units inevitably tended towards a solution in which the urban units occupied areas with minimum perimeters.* This enabled the adjoining rural units, although still extremely elongated, to have a shape which is suf-

* The shape which has the minimum perimeter for any given area is a circle. Even in extreme cases like Winnipeg, however, external contiguity could be satisfied without reaching this limit.

Sample	Mean weight (gm.)
1	0.13080
2	0.13125
3	0.13074
4	0.13115
5	0.13104
6	0.13105
7	0.13053
8	0.13100
9	0.13088
10	0.13053
	Σ 1.30897
	$\bar{X}$ 0.130897

FIGURE 8. Sampling the weight of the steel balls.
Table of mean weights per ball obtained from random samples consisting of ten balls each.
From these samples an overall mean of 0.1309 gm. per ball was derived (by rounding off) and later used for calculations.

ficiently open at publication scale to provide a reasonable target area for screen symbols when the map is eventually used as a base. The problem of steep urban-rural population gradients is much easier to solve in the case of those urban areas which are not entirely surrounded by rural divisions, e.g. Vancouver, Toronto and Halifax. Distortion of rural divisions adjacent to these cities could be reduced by directing the expansion of the urban area towards the bounding shoreline.

In controlling the shapes, therefore, a considerable degree of conformality was attempted, so that graticule lines intersected each other as close to 90° as possible. For the purpose of initial building, ±15° was regarded as a reasonable aim. Although this specification could not be adhered to in areas of extreme angular shearing, as in the case of Winnipeg, the general aim was to produce gently curving graticule lines concave towards high population density centres and convex towards sparsely populated areas.

The addition of lakes offered a way to reduce shearing in sparsely settled rural areas. Northern Manitoba provides an example: by adding the lakes, especially Lake Winnipeg, it was possible to extend the 60th parallel along a more reasonable alignment than would otherwise have been possible. Lake Nipigon similarly prevented the northern boundary of Ontario Division 20 from collapsing farther south. The areas allocated to water surfaces on the map have no isodemographic significance. The sizes chosen for lakes and rivers are arbitrary although the choice was governed to some extent by the size and shape of adjacent census units, and by the distortion of the graticule in their vicinity.

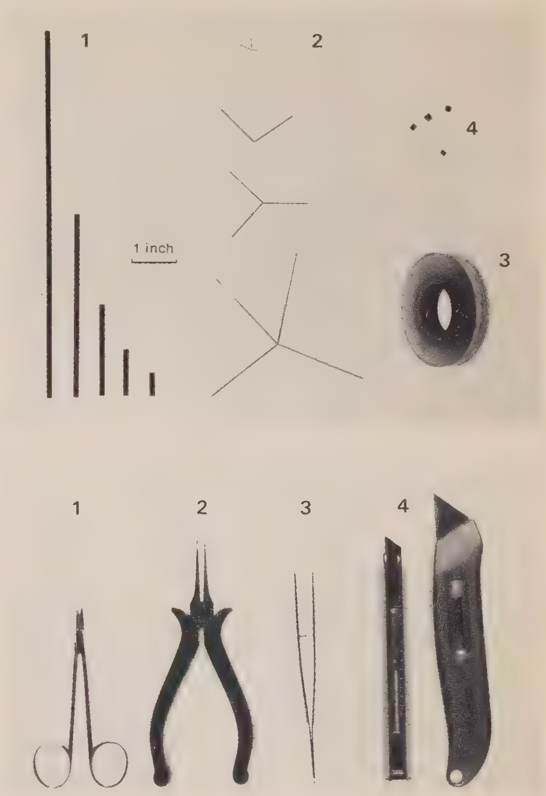

FIGURE 9. Model hardware and instruments.
A – 1. Metal strips cut to varying lengths.
2. Hinged metal strips.
3. Mylar base adhesive tape used for hinging metal strips; a standard roll of 1/2″ tape was cut into three segments on its spool. The centre segment was removed leaving two segments of the required width.
4. U-shaped glides to fit over two overlapping hinge arms.
B – 1. Surgical scissors for cutting metal strips.
2. Pliers for shaping "u" glides.
3. Tweezers for manipulating hinges and glides.
4. Retractable blade knives for cutting tape and rubberoid material.

FIGURE 10. Cluster of partially transformed mapping units. First assembly of units in southern Saskatchewan and southwest Manitoba. The boundary fences were constructed between isomorphic units (see Figure 4B) so that all the units had a larger area than required. The units were later filled with the appropriate number of balls and compacted by applying pressure from the sides and top. The 49th parallel, forming the southern boundary, was built as a straight line with the eastern and western Saskatchewan boundaries being reconstituted as straight lines perpendicular to 49th parallel during compaction. Each hinge represents a point on the boundary determined by the second generalization and is identified by the point's unique number.

The continuous adjustment was accomplished by locking an assembly of units along two sides and then applying pressure to the remaining sides in the direction of the desired movement. Movement of the balls and hinges was restricted to a horizontal direction by placing sheets of 1/4″ "Perspex" over the assembly. This prevented the pressure applied to the sides from dissipating upward and causing the balls to ride over each other. The transparent surface also enabled visual checking of the movement. The exercise could easily be stopped when any of the overlapping hinge arms reached a maximum overlap, in which case the side could no longer shorten, or when the arms reached maximum extension and a gap would have developed.

When hinge arms reached maximum overlap they could either be shortened by cutting a segment off *in situ* with the aid of special surgical scissors, or the whole hinge could be replaced by one with shorter arms. Conversely, when hinge arms reached their maximum extension, the hinges could be replaced by ones with longer arms or an extra strip overlapping both arms could be inserted to allow further expansion.

The large size of the physical model meant that it could be assembled by building several regions separately and simultaneously. These could then be moved across the assembly table, vastly simplifying the final shaping (Figure 12). These sections were built with a layer of mylar drafting film separating the balls from the table and the finished assemblies could then be rafted around on the table without distorting their shapes. When the main regions were assembled in their approximate final positions, the intervening census units were added. The final shaping was then completed.


EDMONTON
VANCOUVER
WINNIPEG
OTTAWA
TORONTO
49°
50°
125°
130°
55°
60°
65°
70°
140°
120°
115°
110°
70°
105°
100°
95°
90°
70°
65°
60°
123°
120°
115°
110°
105°
100°
85°
80°
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85°
78°
75°
42°
83°
80°
43°
42°

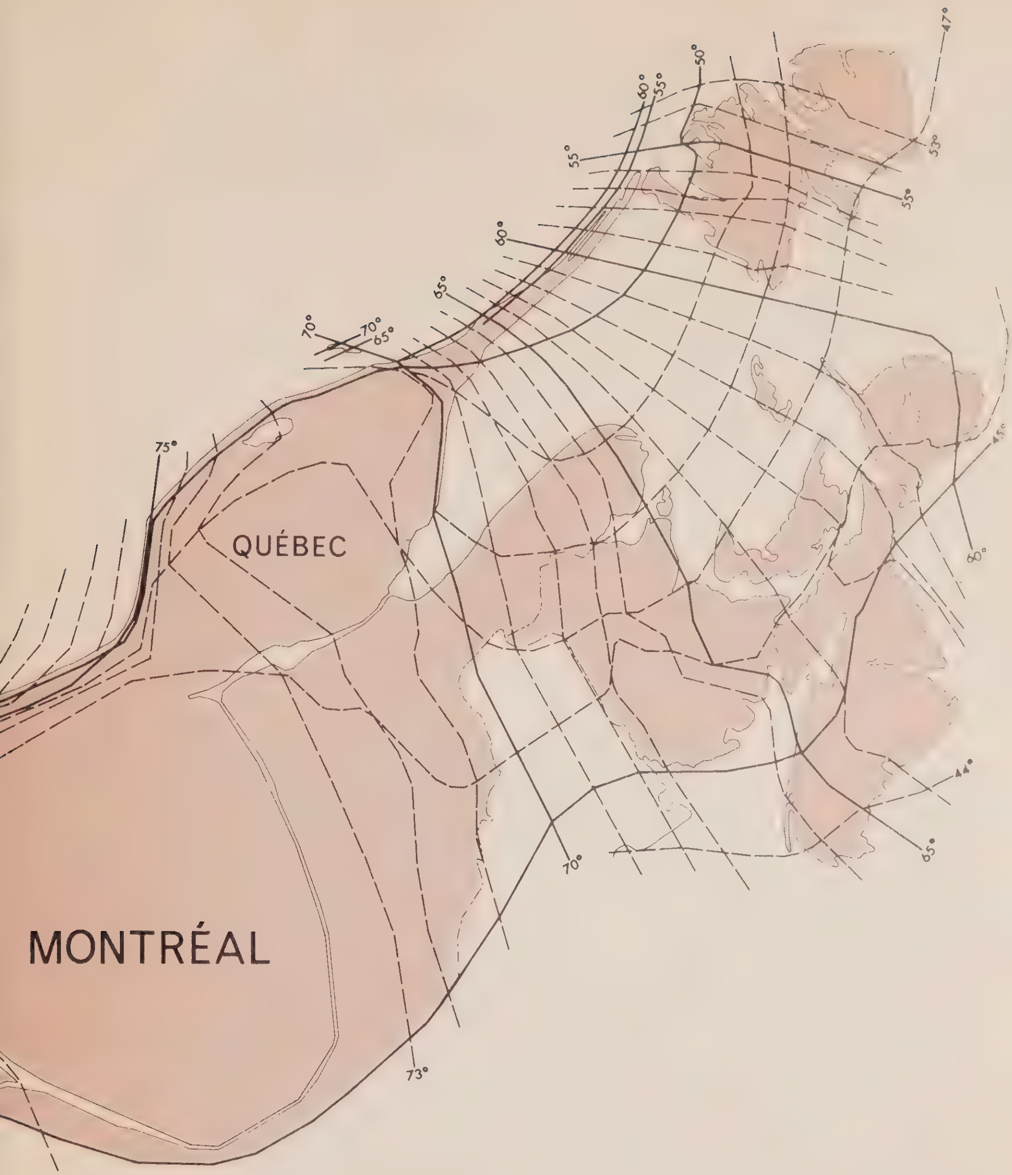


FIGURE 11. Graticule of the Isodemographic Map of Canada.
From the pattern of the graticule the urban and rural areas can easily be discerned; the close spacing indicates the sparsely populated regions, the wide spacing being indicative of urban areas with the transition between the two producing the most marked disconformities.

This final shape was checked and the outside boundary of the model stabilized to keep the model rigid in a horizontal plane. This was achieved by filling the gap between the model and the edges of the assembly board with 1/8″ rubberoid floor tiles. Segments of the model outline were traced on drafting film and transferred to tiles which were cut to shape. The shaped tiles were then inserted in their places on the board. This process, illustrated in Figure 11, continued until all the gaps on the assembly board were filled.

Terminal stage

With the model securely locked in position, the final stage of developing a useable map began by tracing the census division boundaries (as defined by the metal strips) onto stable base drafting film. Each division was identified and its area measured with a planimeter. Large differences between the expected and the actual areas of units indicated errors in weighing or counting of the balls. Such units were corrected on the model, appropriate adjustments to local shapes were made and the new boundaries were then retraced and remeasured.

It was mentioned earlier that in preliminary calculations, 64 balls (with individual diameters of 1/8″) were assigned to represent an area of one square inch. It was assumed that a cluster of balls would compact so as to occupy a maximum plan area, the balls arranging themselves so that their common tangents formed squares. At the other extreme, the balls would occupy a minimum plan area if their tangents formed hexagons (see Figure 13). On the actual model, both patterns occurred in combination. The primary factors determining the area occupied by a given number of balls in the model appeared to be the size of the census unit, number of sides and the size of its vertex angles.

Compaction trials conducted prior to model building indicated that, in polymorphic clusters bounded by metal strips, differences between calculated areas (at 64 balls per square inch) and the actual areas produced by the model units would be of the order of ± 10 per cent. Small units with acute angles, and elongated units formed by a single line of balls (see Figures 14D and 14E) were expected to yield areas larger than calculated. Very large units, in which most balls tend to compact to minimum areas (Figure 14C), were expected to produce substantially smaller areas than calculated.

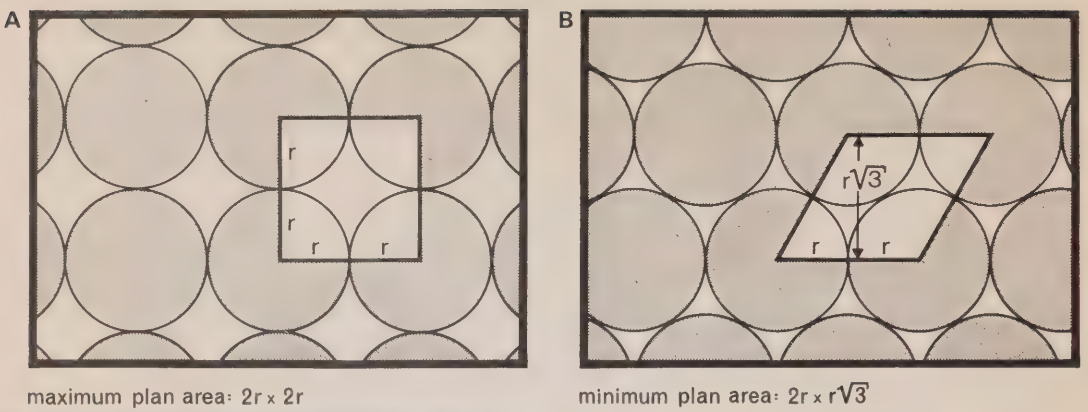
At the time the project was undertaken, no quantitative limits had been prescribed as a standard of acceptability. As a result of discussions between the

FIGURE 12. Joining of model segments.
Three segments of the model placed in proper juxtaposition: left — Eastern Townships of Quebec (with part of Montreal on far left); centre — Gaspé Peninsula and New Brunswick; right — Nova Scotia. When in position, the segments were linked by building the appropriate divisions between them.

FIGURE 13. Stabilizing the model boundary.
The outside boundary of the completed model was stabilized by filling the space between it and the edge of the board with 1/8″ thick rubberoid tiles.

A – the detail of the outside boundary being traced on mylar drafting film.

B – rubberoid tile being cut following the transfer of detail from the drafting film. The cut and shaped tile was then placed in its appropriate position around the model.



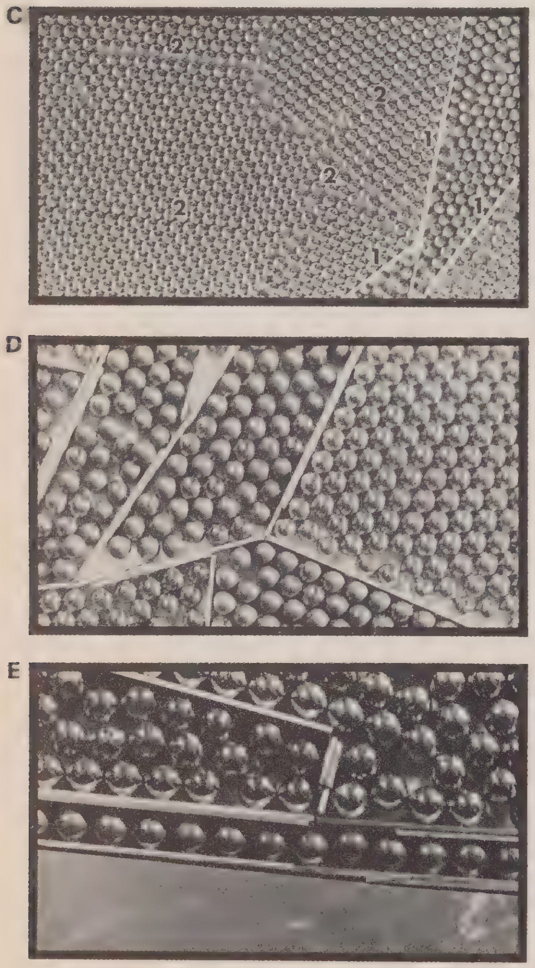


FIGURE 14. Patterns of compaction.

A – Arrangement in which a ball theoretically "occupies" a maximum plan area. This area can be expressed as $4r^2$ where r is the radius of the ball.

B – Arrangement in which a ball theoretically "occupies" a minimum plan area, i.e. $\sqrt{12r^2}$.

C – Photograph of the model around southeast corner of Edmonton:
1 shows metal strips representing the census division boundaries;
2 shows zones of disconformity between regularly compacted balls; zone widths are governed by the angle between the boundary segments inducing the initial compaction.

D – Section of model showing the effect of the boundary configuration on compaction in medium-size units.

E – Enlargement of a division represented by a single row of balls; note the additional area occupied by the inner hinge arms making the single ball width unit too large.

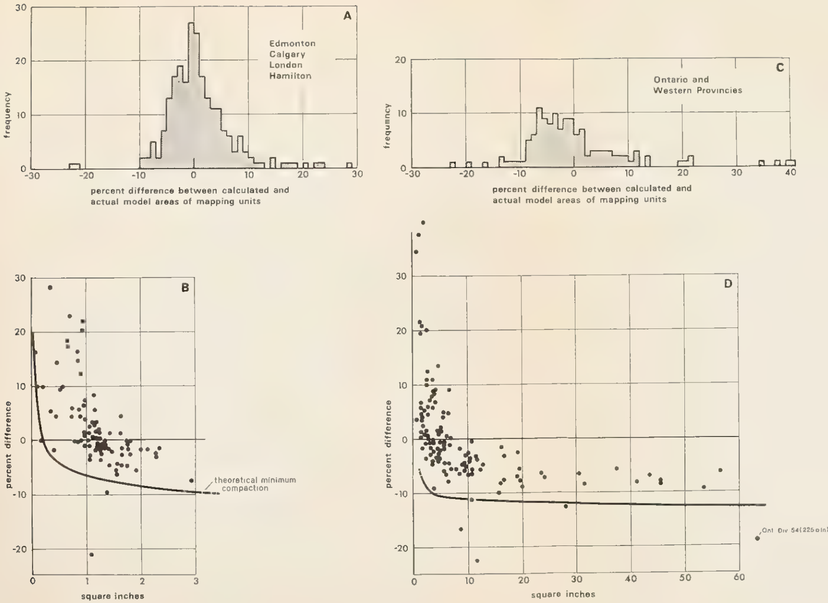


FIGURE 15. Compaction statistics.

A – Frequency distribution of per cent difference ("error") between calculated areas of census tracts and their actual model areas for census tracts of Edmonton, Calgary, London and Halifax. The mean "error" for this sample was less than 1/2 per cent

B – A scattergram of points from the same sample as in A correlating the "error" with census tract size. The "theoretical minimum" line represents the mean minimum of a theoretical set of units calculated to occupy minimum plan areas (as in Figure 13B) while forming a square as nearly as possible. The scattergram indicates an inverse correlation between unit size and compaction "error." The points substantially below the theoretical minimum line indicate units with incorrect number of balls.

C – Frequency distribution by "error" size for census divisions of western provinces and Ontario. The mean "error" for this sample was –3.9 per cent. This comparatively large "error" was due to the fact that the divisions are larger units relative to the urban tracts and therefore ball compaction into a minimum plan area pattern had greater effect.

D – A scattergram of points representing the same units as in C confirming the inverse correlation between "error" and unit size.

authors and the federal representatives managing the research contract, the following limits were agreed, as percentages of population expressed in terms of area:

Census metropolitan areas of Montreal, Toronto and Vancouver	2%
Divisions containing cities with population over 100,000	4%
All other divisions	8%
Individual urban models	5%
Individual census tracts	10%

It may be asked why such limits are necessary: in theory the map could be made perfectly accurate, except for errors caused by the need to draw a line of visible width separating census divisions from each other. This optimizing process would, however, require an inordinately long period of mechanical and graphical adjustment and it is doubtful whether, even if time and money had permitted, the results would have been worthwhile. As a comparison, the specified limits are well within the range of areal accuracy of medium and small-scale convention maps. For example, a map on Lambert conformal conic projection, such as used in the *National Atlas of Canada,* has a built-in areal error greater than 2 per cent in a zone of about 20° between its two standard parallels. The specified tolerances are quite small and, when the map is reduced to its published form, would be barely noticeable when compared with a perfect solution. More important, what is being mapped is itself both imperfect and dynamic: no census is entirely accurate and, even if it were, it would be true only of a moment in time. Changes in the size and distribution of the Canadian population are continuous and a 'perfect' solution would be little more realistic than a close approximation. If extra resources were available, more useful improvements could be made to the shape of the map than to its area.

Each census unit was measured with the aid of a planimeter; the measurement was recorded and then compared with its calculated area. The results of the preliminary measurements were graphed and are presented in Figure 15. The mean difference between the calculated and the model areas of the census divisions in western Canada and Ontario was found to be −3.9 per cent. This indicated that the actual scale of the model, on the average, was approximately 9,300 people per square inch. Acceptance of this scale as the new scale of the model shifted the mean, and thus brought most of the units within the range of acceptable accuracies. Expected areas, according to the new scale, were recalculated for each census unit and again compared with their model areas. Units outside the limits of accuracy were corrected graphically by an appropriate shift in boundary. Peripheral units were naturally the simplest to adjust since their outside boundaries could be readily moved. At this stage, generalized boundaries of the Census Metropolitan Areas, the main Census Major Urban Areas and the two other provincial capitals (Charlottetown and Fredericton) were added graphically.

With the area of each division checked and corrected, the boundary detail which had been generalized during model building could now be reinstated. In the preparatory stage, a segment of a model boundary [illegible] been established by drawing a line of best fit to the points defined by changes of direction. Now, in the final plotting, these points were relocated about [illegible] appropriate segment of the model boundary, [illegible] establishing their relationship with the initial line [illegible] fit. This technique is illustrated and elaborated [illegible] Figure 7.

On a land-based map with a uniform density [illegible] topographic detail, population varies from place to place. When the map is transformed so that the population density becomes uniform, the density [illegible] topographic detail becomes higher in rural areas and least in the centres of urban units. This principle provided the necessary guidance in plotting boundary and other detail.

The model itself established control at the level of census divisions only and, as such, provided for uniform generalization at that level. Insertion of Census Metropolitan Areas and Census Major Urban Areas introduced units which were, in most cases, subdivisions of the primary mapping units. This, in effect, required a level of detail of an order not provided for by the divisions. This complication was alleviated by introducing local distortions in terms of locating boundary detail and the graticule.*

Finally, topographic detail and graticule were plotted on the model tracing. The relative position of this detail is, of course, accurately located only where it crosses or coincides with division boundaries. Elsewhere on the map, the position of such detail has been interpolated.

In the case of the urban models, the mean difference between the expected and actual areas was found to be close to zero (see Figure 13): the models were very close to their anticipated scale of 4,480 people per square inch. Units which did not meet the specified accuracies were corrected by either removing or adding balls. Rivers of arbitrary and uniform width were then inserted into

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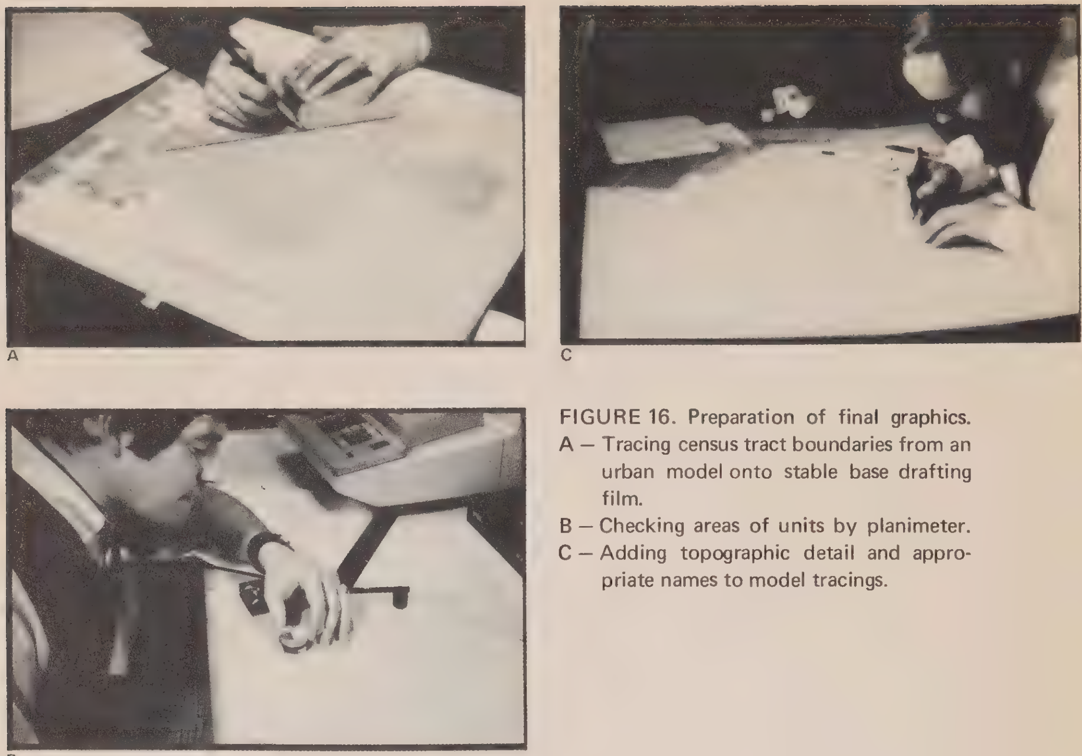
* This distorted graticule and similarly distorted topographical detail were specified as project requirements, because it was envisaged they would be necessary to help the map user find his way about the map. The urban areas provide adequate guidance but the graticule and topographic detail tend to be distracting. They have therefore been omitted from the published map.



A

C

B

FIGURE 16. Preparation of final graphics.
A — Tracing census tract boundaries from an urban model onto stable base drafting film.
B — Checking areas of units by planimeter.
C — Adding topographic detail and appropriate names to model tracings.

the models to aid internal location by the user. City and municipal boundaries, highways and some major streets were similarly added to model tracings. As on the main map, the position of such topographical detail is also approximate if it does not coincide with census tract boundaries.

The urban models were constructed separately from the main model. During building, the general shape of their outer boundaries was retained since there were no problems of contiguity with adjacent rural areas. Consequently, and as anticipated, their form, even if reduced to the isodemographic scale of the main map, could not be incorporated in that map. The utility of the main map would be considerably improved if it were further subdivided into census subdivisions and census tracts. Such work and other improvements might be appropriate subsequent to the 1971 census when the new census data could be incorporated at the same time.

The completed maps

Urban maps

The initial aim in building the urban models was to achieve a transformation which was correct within the basic controlling parameters of population and internal contiguity. In addition, the deformation during building was controlled to a considerable extent following principles outlined earlier. The initial results could then be successively readjusted to achieve the closest possible approximation of the initial geographical shape. The cumulative results of successive readjustment phases could first achieve a satisfying solution, then an optimizing one and finally tend towards a maximized result. In this succession, effort and time expended soon reaches a stage of diminishing returns.*

In Figure 17 three stages of successive approximation towards conformality are illustrated. The last stage of the sequence (Figure 17D) shows a high degree of angular conformity with the initial land-based map (Figure 17A) and represents an optimizing solution. The process of adjustment between the highly anamorphic first stage (Figure 17B) and the reasonably conformal optimal stage appears to be characterized by diminishing sum totals of the boundary lengths. Boundaries of units were summed for each of the three successive stages of transformation illustrated in Figure 17. The summed lengths were found to be the highest for the initial anamorphic stage and least for the most conformal version. These results were graphed and are presented in Figure 18. Although intellectually plausible, this single observation is inconclusive and the hypothesis requires further proof. Further investigation was outside the scope of this project, but it may be worth investigation in future work on these or similar maps. Briefly, the proposition is: the condition of a successful transformation requiring close conformality, should attain, on the average, the minimum boundary lengths of the component units.

Confounding variables that may disturb such a simple relationship are introduced by large peripheral (i.e. outer suburban) units with low population density and even census tracts with no population at all. The first category is characteristic of the fringe areas of most cities. The second is found in Toronto and Montreal, where parks and marshalling yards were delineated as separate census tracts to isolate their special characteristics. This practice, highly desirable in the case of land-based maps, is unnecessary for the purpose of isodemographic definition since the territorial extent of a census tract is irrelevant. Zero population tracts (Nos. 19 and 34) containing High Park and the adjacent lakeshore of Toronto were eliminated and their neighbouring units thus became the new boundary of the lakeshore.

This simple device could not be applied to tract No. 174 within the City of Montreal. This tract coincides with Parc Maisonneuve and is completely surrounded by tracts that can be defined in terms of isodemographic area. To avoid contiguity problems that would arise if the tract were not represented on the isodemographic map, it was considered as combined with one of its adjoining units.

Most of the twelve urban models were constructed and adjusted to a level where they represent a satisfying solution. The map of Edmonton is an exception to this and it may give some idea of what could be done for the other cities with additional time and effort. Possible future work could include further detail to widen the scope for greater application and this is discussed in Chapter IV.

* It is, of course, difficult to specify the ideal solution, and equally difficult to judge when it has been achieved. The quality of the product must ultimately be judged by the map user.

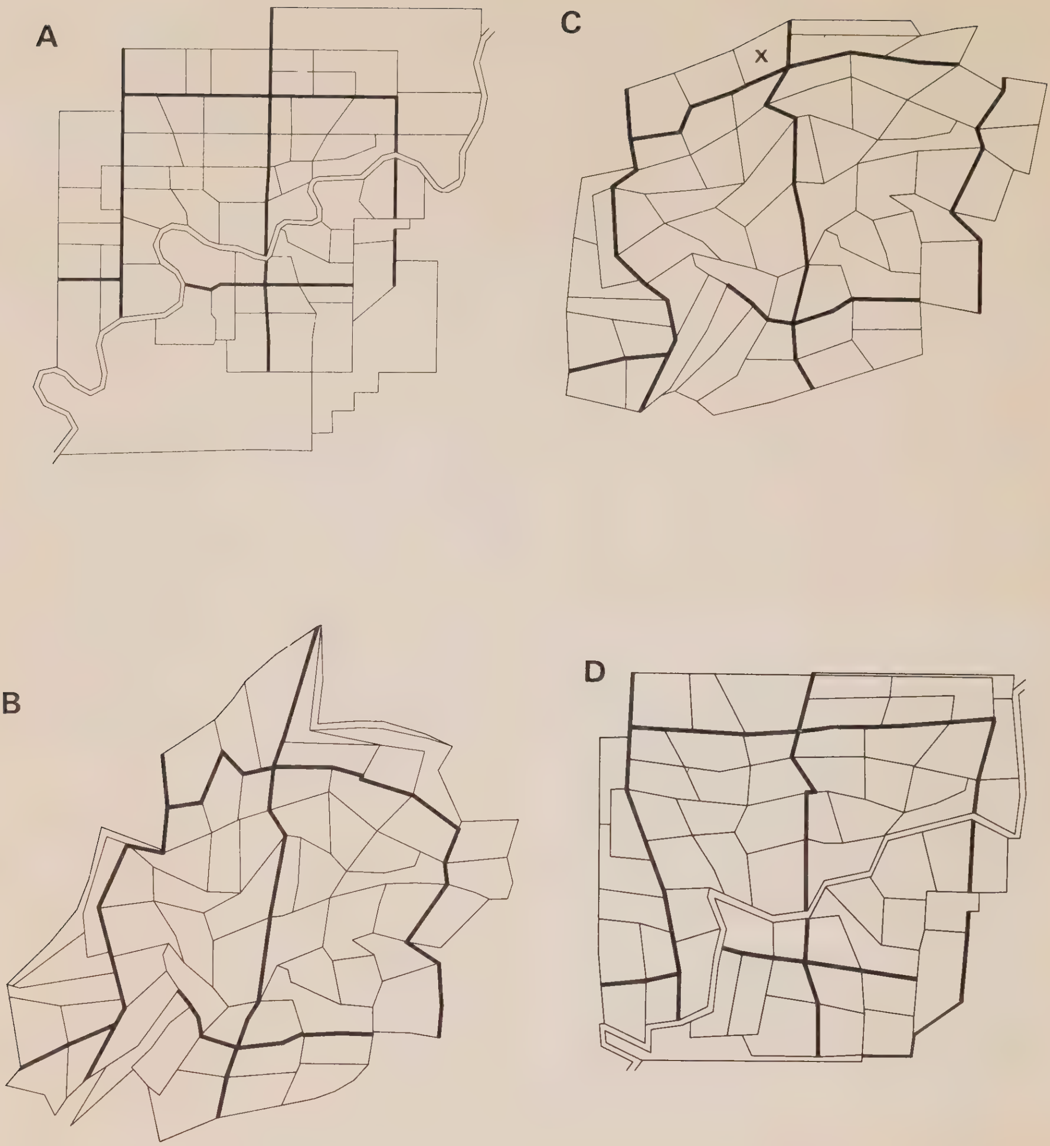


FIGURE 17. Successive shape transformations: Edmonton.

A – A conventional map on UTM projection showing census tracts. The heavy lines were added for easier identification in the following transformations:

B – A highly anamorphic first transformation into an isodemographic map.

C – First transformation after major adjustment; tract marked X appears significantly smaller than it does in B. This discrepancy was detected during systematic checking and corrected at the final stage.

D – Final shape after second major adjustment. At this stage the river was reinserted to aid user recognition. Units left off from the previous two stages because of size, were added graphically.

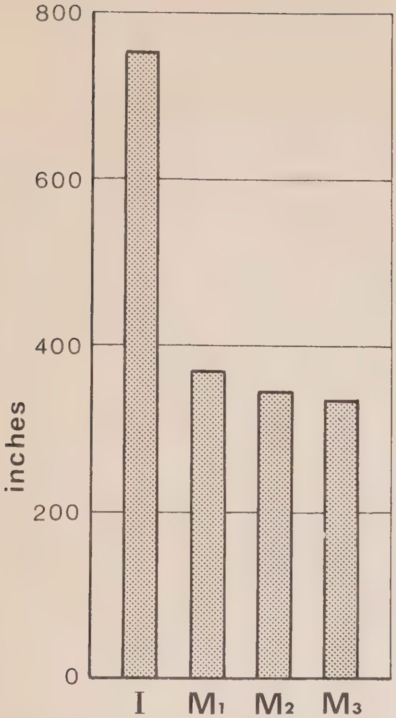


FIGURE 18. Summed perimeters of successive shape transformations.
A bar graph showing the changes in the cumulative perimeter lengths of census tracts associated with the shape transformations in Figure 17. Column 1 represents the summed perimeter lengths of the generalized isomorphic units which were at the same demographic scale as the assembled units in Figure 17B, C, D. Columns M1, M2, M3 represent the summed perimeters of units associated with the successive shape transformations of the isodemographic map in Figure 17B, C and D respectively.

Map of Canada

The present shape of the main map attempts to simulate some of the characteristic features portrayed on a conventional map on a Lambert conformal conic projection. It was considered desirable to provide initially an output with a close affinity to the most frequently used projection for Canada, although other, geometrically more elegant, solutions were possible. The final shape takes into account the curvature of the parallels found on the Lambert projection but allows a somewhat disproportionate vertical collapse. This vertical collapse is accompanied by complementary east-west elongation producing substantial shearing in the sparsely settled northern regions of the country.

In western Canada an attempt was made to keep the 49th and the 60th parallels as gently curving lines parallel to each other. This arrangement preserved the character of the southern border and produced an acceptable shape of the provinces. On the other hand, this constraint forced the intermediate parallels to weave drastically around the large urban areas. The parallelism of the 49th and the 60th latitudes also strongly influenced the shapes of Manitoba and British Columbia. In these two cases it was necessary to "stretch" these provinces in a north-south direction to fit the established length of Alberta and Saskatchewan. Despite the small population of the Yukon and Northwest Territories, and despite the contiguity problems which arise when mapping the N.W.T. (i.e. because it is contiguous to all four western provinces), the convergence of the meridians permits these territories to be mapped as enclosed figures and not quasi-linearly. It would obviously not be possible to lengthen the 60° N parallel beyond its present form and still retain the Northwest Territories as a cartographically useful shape with their present population. Conversely, the isodemographic shape of the N.W.T. could be further improved only by increasing the meridional convergence which would then cause further north-south elongation of the provinces.

The basic structural shape elements of the isodemographic map can be reduced to two lines forming a widely opened letter "y." The short element of the letter represents western Canada and the long stroke includes the population from Windsor along the St. Lawrence River to Newfoundland. Where these two arms join, around Ottawa, becomes an approximate isodemographic centre of gravity. By varying the angle at this "hinge" different shapes could be achieved. In the published map the St. Lawrence River was aligned so that the relative azimuth of the Atlantic Provinces approximated the Lambert conformal conic situation. This arrangement caused substantial shearing in the northern part of Quebec. Northern Quebec proved a particularly difficult area to represent because of its low population compounded by its isodemographic proximity to the largest population centre of Montreal. The published map retains reasonable configurations around the St. Lawrence River and the Gulf of St. Lawrence at the expense of a realistic definition of the James Bay shoreline.

In northwestern Ontario, populations are small and the census divisions contrast markedly to their isodemographic area. This makes it difficult to achieve a satisfactory link to contiguous divisions in eastern Manitoba, since the Canadian Shield edge is close to the provincial boundary and population densities are

generally higher in southeastern Manitoba than in northwestern Ontario. Southern Ontario, because of its large population, transformed into relatively large areas. Much of the resultant distortion was satisfactorily accommodated in a direction towards Lakes Erie and Ontario and away from the Quebec–Ontario border. This allowed the retention of only some features of the Bruce and Niagara peninsulas. In the Atlantic Provinces, the generally close resemblance to the conventional map is due to two factors. First, areas such as Prince Edward Island, Newfoundland and much of Nova Scotia have substantial rural populations combined with an absence of major cities. Second, a very large proportion of the census divisions includes coastal portions where distortion (especially caused by cities such as Halifax and St. John's) can be accommodated relatively easily.

During the transformation, first priority was given to preserving the general shape as far as possible. Next in priority was the shape of the census divisions containing large urban centres. Third priority was given to the shapes of other individual divisions. All these adjustments, of course, were undertaken without departing from the basic requirements of correct isodemographic area and contiguity of adjacent units. Although a number of further improvements are possible and desirable, the present map meets all the requirements set as the initial objectives and may be regarded as tending toward an optimizing solution.

Discussion

Map or cartogram?

At the time this project was being planned, the authors suggested that the output should be described as an isodemographic map. The adjective conveys the basic property of the project: that it assigns equal map space to each person. The name also conveys the authors' preference for using the term "map" instead of the more ambiguous "cartogram."

The definition of a cartogram is indeed vague, even in cartographic literature. The name itself implies that the object is some kind of a diagrammatic map. This in itself helps little to clarify the term and infers that it is an abstraction of an abstraction. Raisz, in fact, defines a cartogram as a diagrammatic map and in the subsequent elaboration states that

> Every map is abstracted to some degree; where the line is drawn between map and cartogram depends on the point of view. Some foreign authors call every single-factor map, such as a rainfall map, a cartogram. Here we. . . limit ourselves to highly abstracted maps where actual outlines or locations are distorted, or to maps which express motion,. . .or such mathematical concepts as centrograms. (Raisz 1962)

From the categories listed above, it is not clear which particular characteristics may be used to distinguish a map from a cartogram. The varying usage of the terms in geographic and in cartographic literature does little to clarify the problem. Balchin and Coleman, exploring the nature of computer barriers in cartography, for example, classified maps into: cartogram maps, isogram maps, morphogram maps and compound maps (Balchin and Coleman 1967).

The difficulty perhaps stems from the conventional definition of a map as an analog model of the earth's surface. Defined in that way a "map" can represent only a limited number of physical features in their basic planimetric or topographic form. This historical definition, however, has long been rendered obsolete by the prodigious output of schematic cartography, which effectively extended the definition to that of an analog model of phenomena in the biosphere and beyond. The fact that phenomena presented in this form are often theoretical constructs, without tangible or apparent existence in reality (e.g. maps showing variations in average income, rate of population change, crop value, etc.), are less important than the fact that their spatial characteristics are best expressed in a cartographic form. Similarly, distortion is not an overly useful criterion to distinguish cartograms from maps, since anamorphism is an inherent basic property of maps. All maps attempt to represent the whole or portions of a three-dimensional spherical surface on a flat piece of paper. Anamorphism, therefore, could be used only in relative terms.

From the present usage, it appears that the term "map" often carries a generic connotation covering an extensive range of cartographic presentations. The authors therefore feel that it is entirely appropriate to regard the output of this project as maps, especially as they display most of the essential properties of maps, such as scale, selectivity, emphasis, and symbolization as well as clues to relative and absolute location.

Developing this a little further, the Isodemographic Map of Canada at the model stage had a scale of 9,300 people per square inch, i.e. 1 person was represented by an area approximately $(.01'')^2$. From this, a linear measure can be derived by using a square root factor. This linear measure can be systematically applied throughout the map since a basic assumption in its construction is that the population is evenly distributed and continuous within division boundaries. Linear features, such as roads, streets and rivers, could have their relative lengths expressed in terms of the derived "demometric" units of people length. On the published map, for example, Broadway, a main street in

Vancouver, ranks higher than the British Columbia section of Alaska Highway. Likewise, the Humber River, a local stream running through Metro Toronto compares in length with the Fraser River in British Columbia. An unvarying linear scale is of utmost importance for a map if it is to be used effectively as an analytical tool. A point about the proposed demometric units is that they provide uniform scale measure simple to apply in analysis of socio-economic and environmental factors. An alternative linear scale relating to the initial land-based measure would be difficult to devise since the initial geographic space has been considerably deformed. On a conventional population density map, the scale relating to land is fairly uniform while the population density varies from place to place. On an isodemographic map this relationship is reversed: the population density becomes uniform and the land scale, and therefore the density of physical features, varies.

This distortion of geographic space, with its concomitant distortion of physical features, becomes cartographically acceptable if viewed in terms of the apparent importance of such features by their neighbouring population.* In map terms, a physical feature can be shown on an isodemographic map only if it is definable in terms of population. It therefore follows, that if a physical feature is definable, its relative size should be directly proportional to the magnitude of the population surrounding it.

One of the basic properties of a conventional map is that its initial abstraction can be supplemented by further detail added in a systematic and consistent manner. Although the map space of an isodemographic map relates to humanity, it is also cartographically consistent to plot accurately linear features on such a map. The only prerequisite to the plotting procedure is that it must define a population subunit in the process. Such subunits need not be restricted to administratively defined communities. A small population cluster located between a river, a highway and a railway, if delineated in terms of its correct population and contiguity, will yield a boundary enabling the positions and lengths of the respective bounding features to be indicated. To satisfy the contiguity requirements, the whole of a major unit should be subdivided at a time. There are then only two practical restrictions to the amount of detail that could be shown on such a map: plotting scale and the availability of appropriate population data.

* Without pushing the argument too far, it could be maintained that the "isodemographic" significance of Broadway vis-à-vis the Alaska Highway is a measure of their relative importance, *at least in terms of their adjacent populations.* This may be why Canada is content to blacktop one but not the other.

In construction of the present map, isodemographic map space was assigned only to the land segment of a population territory. It was assumed that water areas could not be occupied and therefore could not be represented isodemographically. Although this did not preclude showing inland waters on the map, it provided no objective method for determining their map size. This problem could perhaps be solved in future modifications by using the measure of demometric units to determine their appropriate areas. Possible procedure could treat water bodies as normal mapping units by assigning them population density equal to that of their surrounding census units. This would provide for a systematic determination of their map size.

Inclusion of inland water bodies as well as the addition of planimetric detail would clearly be beneficial in aiding user recognition. Such additions should also provide more meaningful units for larger scale analysis at local and regional levels. The present maps are based on 1966 census figures and need modification if the 1971 census data are to be plotted accurately.* Additional detail to the map could thus be combined with the basic modifications of the map dictated by the new census data. Further modification to the general shape could also be done at that time. One such modification worth investigating would involve further east-west shortening in the northern areas to alleviate some of the extreme shearing and to provide a more realistic definition of the northern coastline. The lines along which such modifications might proceed could be obtained from analysis of the present graticule element and through feedback from users.

Although this report is concerned with the techniques of construction of the present map and not with its revision, some comments are appropriate. A critical factor in the decision to develop the isodemographic map by means of a physical model was the inability to specify a desirable form of the output as an initial constraint. This precluded (or at least made much more complex) the use of an analytical approach using a computer. This limitation no longer applies. It should be possible, with the experience of the 1966 map, to specify fairly easily the necessary constraints and then to update the map regularly and swiftly as new census data become available.

An alternative solution would be to retain the physical models and to adjust them periodically in the

* It should not be inferred that the present map is unsuitable for mapping 1971- or 1961-census data. Inaccuracies are small, and the 1966 isodemographic map is certainly a better way of conveying 1961 or 1971 data which relate directly to population than are convential maps.

general manner described earlier. Apart from other considerations, however, the fragility of the models must be remembered. It would be difficult to ensure their safe storage and to train personnel in their handling and use. Since computer methods appear to be a satisfactory alternative, the models have been converted into permanent exhibit by fixing the balls permanently in position with transparent resin.

Application and potential use

The objective of the project was to provide a map which would: (1) effectively communicate the urban-rural distribution of the Canadian population, and (2) provide a more valuable framework for analysis and communication of social and economic variables.

It should not need stressing that an isodemographic map is not the only useful means of depicting spatial variations: it cannot replace the conventional land-based map even in the representation of population. It emphasizes one aspect of reality, distorting or omitting others, and in the process of research and analysis can only be used in conjunction with conventional and other unconventional maps which clarify other features of the demographic pattern. The map *does not,* for example, prove or even support the notion of a densely populated corridor between Montreal and Toronto, which is one of the more widely accepted myths of contemporary Canadian geography. If anything, it provides evidence against the corridor concept: the closeness of Montreal and Toronto on the isodemographic map is a measure of the *lack* of intervening population, in the several hundred miles which separate them.

The main usefulness of the isodemographic map should be as a framework for analysis and communications of those socio-economic factors directly dependent on numbers of people (e.g. age and sex distribution, income, education, etc.). In this field the urban maps should be particularly useful because of the present upsurge of interest in urbanization. The visual impact of the classes on the isodemographic base is directly proportional to the numerical value of the population included in each class. The statistical input on the map is retrievable simply by measuring the map-area of the given class to find the population count, which can then be multiplied by the class interval value to arrive at an approximate number of people represented by that class in any given segment of the map. Numerical values can also be readily obtained for segments which are not coincident with census tracts or for areas containing two or more categories.

As a cartographic document the isodemographic map has, in its own right, a potentially important function in communication and education. The true extent and importance of urbanization in Canada is almost certainly insufficiently appreciated by most of the population, even though the vast majority are themselves city dwellers. If this communication function is to be effective there is need for some feedback of the reactions of map users to be communicated to the cartographer. This, in turn, should help the cartographer provide more effective and useful maps in the future. The isodemographic map, since it is both novel and of potential interest to a substantial proportion of the population, would be an excellent basis for a systematic sampling of user reaction to unusual maps, thus providing such a feedback.

Summary

This report describes the method used to construct a map in which areas of census units are proportional to their population. Such a map is required to communicate accurately and effectively the urban character of Canada and to provide an appropriate base for display and analysis of socio-economic variables. A mechanical approach to construction was chosen from the alternatives of graphic, mechanical and mathematical methods. The choice was dictated first by the large number of census units to be mapped and second by the fact that mathematical functions for transformation of land shapes to demographic shapes were unknown.

The development of the map depended on the construction of a physical analog model consisting of 1/8″ diameter steel ball bearings, in which each ball represented 140 people. An important aspect of the method was that a predetermined number of balls could be contained in an arrangement of metal strips representing census division boundaries and then compacted to occupy a predetermined area proportional to the population of the census unit. The shape of the resulting assembly, representing census units in correct contiguity, was adjusted manually and graphically until a reasonable approximation of the land shape of Canada was achieved. In addition, separate models, at a scale of 70 people per ball and using census tracts as basic mapping units, were made of the twelve largest urban centres with populations over 200,000 people. The models fulfilled the purpose of establishing a correct, but generalized framework to which boundary detail and topographic features were added graphically.

This graphic output is called an isodemographic map, which indicates the basic property of the map: that population is represented by equal map space. Since the map distorts and even omits geographic space, a new concept of demometric units is proposed to facilitate consistent linear measurements.

The inherent characteristic of the isodemographic map is the immediate visual correlation between the numerical population values of individual units. This characteristic provides a more rational framework on which to analyze and present factors directly relating to people. The present output is regarded as a first contribution on which improvements are both possible and desirable. It is offered as a useful contribution to the existing range of cartographic techniques.

Appendix
Computer Support

In the planning stages of the isodemographic map project, computer support was envisaged for manipulating census numerical data and for providing graphic output defining the census units. A computer program devised for this purpose served the immediate needs of the project, as discussed in Chapter II, as well as pointing the way toward a possible wider application in computer drafting of census boundaries and to mathematical means of calculating land and inland water areas. With further development the program could also provide a linkage between land definitions of census units and their demographic equivalents on the isodemographic map.

Data preparation

Preparation of source data in a form suitable for computer processing fell into four phases:

(1) defining census boundaries;
(2) assigning unique code to each boundary point;
(3) extracting geographic coordinates for each point;
(4) defining each census unit by a plotting routine.

(1) To define the census boundaries in terms of geographic coordinates, the boundaries had to be located on maps which had an accurate latitude and longitude framework. The census boundaries, as defined by the Dominion Bureau of Statistics[16] were generalized as required and plotted on topographic maps at an appropriate scale, e.g. census tracts in downtown Montreal were plotted on 1:25,000 topographic maps while most of the rural divisions were located on maps at 1:2 million scale. This variation of scale between the highly populated but geographically small urban units and the contrary rural divisions produced a uniform detail density on the final isodemographic maps.

(2) Each vertex point on the generalized boundaries was identified by a code number, the first two digits of which designated the province (a plotting region). The actual point identification within provinces had an allocation of four digits. This number was recorded on the maps alongside the appropriate point. The numbering system was designed to enable the program to process a province or a Census Metropolitan Area at a time by operating on points with the designated regional codes.

(3) Geographic coordinates of each point were extracted manually with the aid of a romer. The coordinates were recorded in degrees, minutes and seconds or in degrees, minutes and decimals depending on the scale of the map from which they were extracted. Coordinates of each point, together with the point's code number, were punched one point per card.

(4) For the purposes of computation and for actual plotting, each census unit had to be defined in terms of its boundary points. The point numbers were recorded and punched in a sequence which specified the plotting routine. Point numbers, beginning with a point in lower left-hand corner, were recorded in a clockwise direction with the first point repeated as a terminal point completing the traverse. The initial card of each routine included the region and subregion code, population and the land area in square miles, if known. The purpose of the last item was to compare the computer generated area with previously derived measurements as a check on accuracy.

Computer processing of source data

The source data before processing consisted of three sets of records: a card deck containing geographic coordinates of each point, a card deck containing routines defining each census unit and a set of maps showing location and an identifying number of each point. The computer processing and the program is summarized below:

1. Input coordinates in degrees, minutes and seconds or in degrees, minutes and decimals.
2. Calculate new coordinates in degrees and decimals.
3. Input plotting routine data, i.e. population and land area of each census unit; string of points defining census units.
4. Convert geographic x,y coordinates to Lambert conformal conic projection coordinates.
5. Compute land area of each census unit from projection coordinates; compare with given area at input, calculate percentage difference.
6. Compute map-area of each census unit in square inches at selected map scales: 1:2 million, 1:1 million, 1:50,000.
7. Compute isodemographic size of each unit in map square inches at a required scale (4,480 people per square inch used in early runs).
8. Compute enlargement or reduction factor for each scale specified in item 6; the factor indicates a linear scale change of a census unit which enlarges or reduces the unit so that its map-area is equal to its required isodemographic map-area.
9. Calculate number of balls required to fill each census unit.
10. Compute ball weight in grams for each census unit.
11. Print out in tabular form, one census unit per line: unit code, population, given land area, calculated land area, isodemographic area, scale change factors for different map scales, number of balls, ball weight, percentage difference between given and calculated land area.
12. Print out in tabular form points defining each census unit: point code and number, geographic x and y coordinates, projection x and y coordinates.
13. Print out on "Calcomp" plotter a map of a census region (province or urban area) at a specified scale; print out in columns constituent census units at a specified isodemographic scale.

1	2	3	4	5	6			7	8	9 PAGE 1
DIVISION	POP	AREA	COMP AREA SQ MI	ISDS SQ IN	MODEL RATIO 2000000	1000000	50000	NB	WGM	AREA ERROR
11101 1	813	0.0	21.615	0.18	0.0029	0.0058	0.1161	12	1.571	0% EST
11101 2	771	0.0	19.723	0.17	0.0030	0.0059	0.1184	11	1.440	0% EST
11101 3	12145	0.0	6.660	2.71	0.0202	0.0404	0.8085	174	22.777	0% EST
11101 4	12332	0.0	6.324	2.75	0.0209	0.0418	0.8360	176	23.038	0% EST
11101 5	6315	0.0	1.148	1.41	0.0351	0.0702	1.4039	90	11.781	0% EST
11101 6	9998	0.0	2.195	2.23	0.0319	0.0639	1.2777	143	18.719	0% EST
11101 7	8966	0.0	2.871	2.00	0.0264	0.0529	1.0580	128	16.755	0% EST
11101 8	4496	0.0	5.164	1.00	0.0140	0.0279	0.5586	64	8.378	0% EST
11101 9	6154	0.0	0.632	1.37	0.0467	0.0934	1.8681	88	11.519	0% EST
11101 10	5388	0.0	0.535	1.20	0.0475	0.0950	1.8992	77	10.079	0% EST
11101 11	5956	0.0	0.705	1.33	0.0435	0.0870	1.7407	85	11.126	0% EST
11101 12	4248	0.0	1.744	0.95	0.0234	0.0467	0.9343	61	7.985	0% EST
11101 13	9964	0.0	0.896	2.22	0.0499	0.0998	1.9962	142	18.588	0% EST
11101 14	5788	0.0	0.608	1.29	0.0462	0.0923	1.8466	83	10.865	0% EST
11101 15	5490	0.0	0.840	1.23	0.0383	0.0765	1.5307	78	10.210	0% EST
11101 16	6565	0.0	0.961	1.47	0.0391	0.0782	1.5647	94	12.305	0% EST
11101 17	4769	0.0	0.774	1.06	0.0372	0.0743	1.4862	68	8.901	0% EST
11101 18	9662	0.0	0.767	2.16	0.0531	0.1062	2.1248	138	18.064	0% EST
11101 19	5853	0.0	0.511	1.31	0.0507	0.1013	2.0262	84	10.996	0% EST
11101 20	4024	0.0	2.396	0.90	0.0194	0.0388	0.7758	57	7.461	0% EST
11101 21	3160	0.0	3.003	0.71	0.0154	0.0307	0.6141	45	5.890	0% EST
11101 22	3668	0.0	2.428	0.82	0.0184	0.0368	0.7358	52	6.807	0% EST
11101 23	4868	0.0	4.508	1.09	0.0156	0.0311	0.6222	70	9.163	0% EST
11101 24	7667	0.0	2.388	1.71	0.0268	0.0536	1.0728	110	14.399	0% EST
11101 25	9916	0.0	21.766	2.21	0.0101	0.0202	0.4041	142	18.588	0% EST
11101 26	4615	0.0	1.797	1.03	0.0240	0.0480	0.9595	66	8.639	0% EST
11101 27	6324	0.0	0.862	1.41	0.0405	0.0811	1.6216	90	11.781	0% EST
11101 28	5678	0.0	0.855	1.27	0.0386	0.0771	1.5424	81	10.603	0% EST
11101 29	4573	0.0	0.548	1.02	0.0432	0.0864	1.7289	65	8.508	0% EST
11101 30	6389	0.0	0.601	1.43	0.0488	0.0976	1.9515	91	11.912	0% EST
11101 31	6112	0.0	0.845	1.36	0.0402	0.0805	1.6100	87	11.388	0% EST
11101 32	3387	0.0	0.703	0.76	0.0329	0.0657	1.3142	48	6.283	0% EST
11101 33	6693	0.0	0.653	1.49	0.0479	0.0958	1.9170	96	12.566	0% EST
11101 34	6134	0.0	1.039	1.37	0.0364	0.0727	1.4548	88	11.519	0% EST
11101 35	5466	0.0	0.678	1.22	0.0425	0.0850	1.6993	78	10.210	0% EST
11101 36	5106	0.0	0.970	1.14	0.0343	0.0687	1.3738	73	9.556	0% EST
11101 37	4044	0.0	0.723	0.90	0.0354	0.0708	1.4156	58	7.592	0% EST
11101 38	4470	0.0	0.718	1.00	0.0374	0.0747	1.4941	64	8.378	0% EST
11101 39	5223	0.0	1.125	1.17	0.0323	0.0645	1.2900	75	9.817	0% EST
11101 40	5491	0.0	0.766	1.23	0.0401	0.0802	1.6033	78	10.210	0% EST
11101 41	6328	0.0	3.836	1.41	0.0192	0.0384	0.7690	90	11.781	0% EST
11101 42	5085	0.0	1.199	1.14	0.0308	0.0617	1.2331	73	9.556	0% EST
11101 43	4556	0.0	1.073	1.02	0.0308	0.0617	1.2338	65	8.508	0% EST
11101 44	13129	0.0	19.080	2.93	0.0124	0.0248	0.4966	188	24.609	0% EST
11101 45	8005	0.0	0.923	1.79	0.0441	0.0882	1.7635	114	14.923	0% EST
11101 46	7512	0.0	1.184	1.68	0.0377	0.0754	1.5081	107	14.006	0% EST
11101 47	11320	0.0	1.441	2.53	0.0419	0.0839	1.6778	162	21.206	0% EST
11101 48	4455	0.0	0.565	0.99	0.0420	0.0841	1.6812	64	8.378	0% EST
11101 49	3980	0.0	0.796	0.89	0.0335	0.0670	1.3390	57	7.461	0% EST
11101 50	5486	0.0	0.692	1.22	0.0421	0.0843	1.6852	78	10.210	0% EST
11101 51	7581	0.0	1.543	1.69	0.0332	0.0664	1.3271	108	14.137	0% EST
11101 52	6366	0.0	0.949	1.42	0.0388	0.0775	1.5504	91	11.912	0% EST
11101 53	5730	0.0	0.633	1.28	0.0450	0.0901	1.8015	82	10.734	0% EST
11101 54	2641	0.0	9.988	0.59	0.0077	0.0154	0.3079	38	4.974	0% EST

FIGURE 19. Computer printout of numerical data.
A photograph of a line printer output with numerical data for Calgary census tract region. Columns show: 1 — census tract identification number, 2 — population, 3 — land-area, (if given by D.B.S.), 4 — computed land-area in square miles, 5 — isodemographic map-area in square inches at a scale of 4,480 people per square inch, 6 — model ratio factors for three scales, indicating the amount of enlargement or reduction the unit would need to undergo to attain the required isodemographic area, 7 — number of balls to the nearest ball, 8 — weight of balls in grams, 9 — per cent difference between given and calculated land-areas.

Output

A tabular printout with numerical data output is illustrated in Figure 18, showing the first page of data for Census Metropolitan Area of Calgary. To simplify debugging and plotting procedures, a region or a subregion was processed at a time. A region consisted of a province with all its census divisions. Census Metropolitan Areas in which the mapping units were made up of census tracts were designated as subregions.

Each run could also generate a complete listing of points defining each census unit (Figure 19). These listings tabulated the projection coordinates in miles from origin as well as giving geographic coordinates for each point. The listings were particularly helpful in debugging the initial data set of geographic coordinates.

The final output consisted of a "Calcomp" plot of a region or a subregion in two sections. The first section produced a map of the whole region (or subregion) at a specified scale on Lambert conformal conic projection (Figure 20A). The second section defined the constituent census units at a specified isodemographic scale (Figure 20B) printing these in numerical order in columns.

INPUT LOG

X ORG	-455.543
Y ORG	7724.738
SCALE	1 : 50000.
ID CN LAST PRIMARY PCINT READ	11 0

1	2			3	
14	PCINTS DEFINE THE REGION		11 101	1	
514	-886.178	3627.50		50.9216	113.988
509	-887.239	3629.89		50.9513	114.022
508	-887.232	3631.95		50.9801	114.033
512	-884.891	3631.34		50.9801	113.982
522	-884.338	3633.25		51.0090	113.981
521	-885.022	3633.43		51.0090	113.996
520	-883.292	3634.34		51.0281	113.965
518	-883.128	3634.98		51.0377	113.965
519	-882.421	3634.80		51.0377	113.949
517	-881.574	3635.26		51.0471	113.934
516	-883.523	3627.85		50.9362	113.935
513	-885.656	3628.39		50.9360	113.982
515	-885.901	3627.44		50.9218	113.982
514	-886.178	3627.50		50.9216	113.988

7	POINTS DEFINE THE REGION		11 101	2	
501	-893.326	3628.39		50.9080	114.139
500	-892.613	3631.27		50.9510	114.140
505	-889.564	3630.47		50.9510	114.073
509	-887.239	3629.89		50.9513	114.022
514	-886.178	3627.50		50.9216	113.988
510	-887.438	3626.69		50.9056	114.009
501	-893.326	3628.39		50.9080	114.139

6	POINTS DEFINE THE REGION		11 101	3	
500	-892.613	3631.27		50.9510	114.140
499	-891.996	3633.69		50.9871	114.140
511	-891.031	3632.97		50.9806	114.117
504	-889.060	3632.41		50.9800	114.073
505	-889.564	3630.47		50.9510	114.073
500	-892.613	3631.27		50.9510	114.140

10	POINTS DEFINE THE REGION		11 101	4	
505	-889.564	3630.47		50.9510	114.073
504	-889.060	3632.41		50.9800	114.073
507	-887.916	3632.13		50.9801	114.048
506	-887.748	3633.11		50.9947	114.050
471	-887.396	3634.00		51.0083	114.047
491	-886.394	3633.74		51.0083	114.025
492	-886.260	3633.41		51.0042	114.021
508	-887.232	3631.95		50.9801	114.033
509	-887.239	3629.89		50.9513	114.022
505	-889.564	3630.47		50.9510	114.073

FIGURE 20. Tabulation of points defining census units.

A sample line printer output showing tabulation of points that define census units in Calgary. Column: 1 — point number, 2 — projection coordinates in miles from origin, 3 — geographic coordinates in degrees and decimals.

A

B

FIGURE 21 Computer generated line drawings
A sample "Calcomp" printout
A Calgary census tracts on Lambert conformal conic projection
B Individual census tracts plotted to a common isodemographic scale. These units are isomorphic i.e. simple enlargements or reductions of the equivalent units in A

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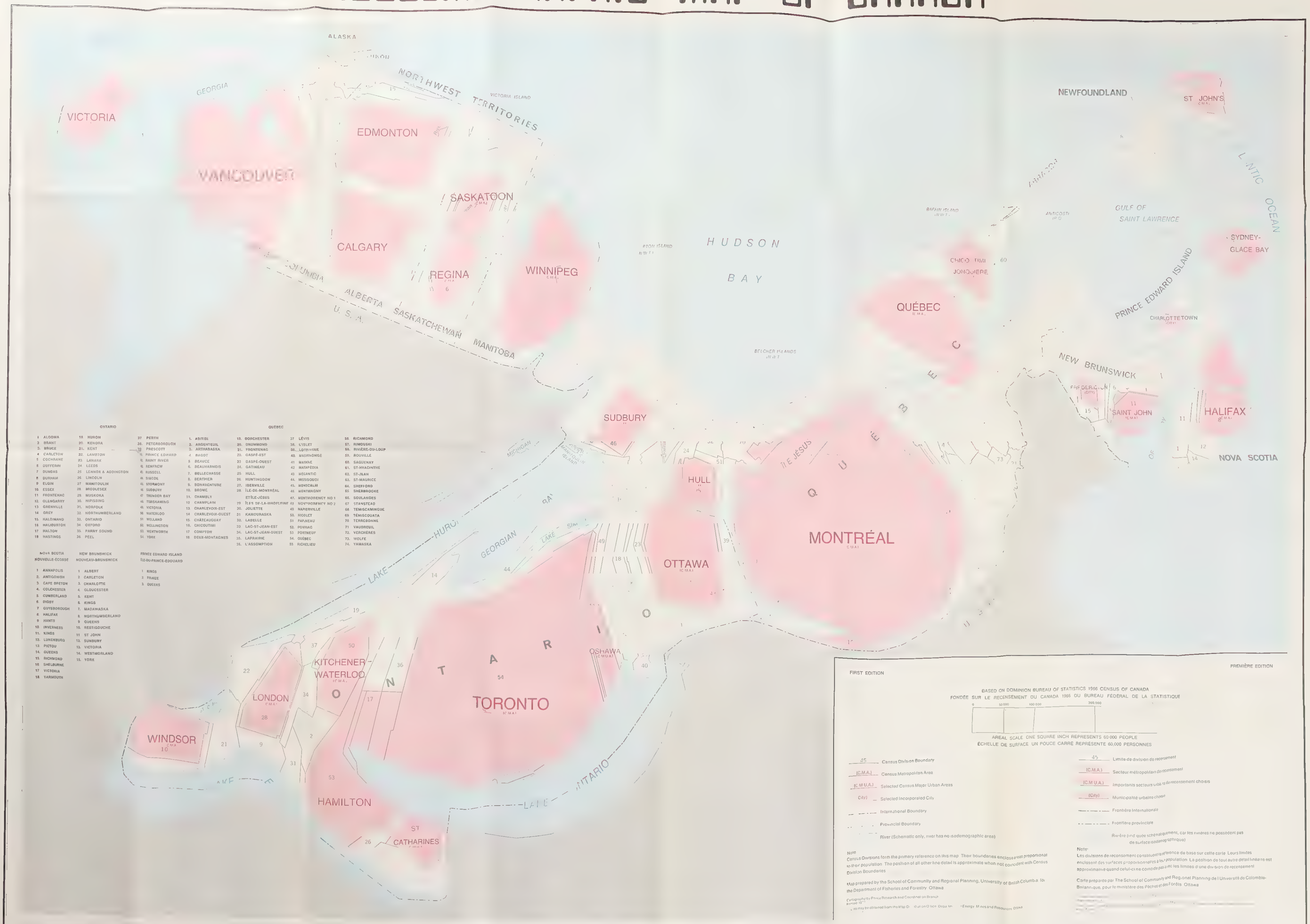
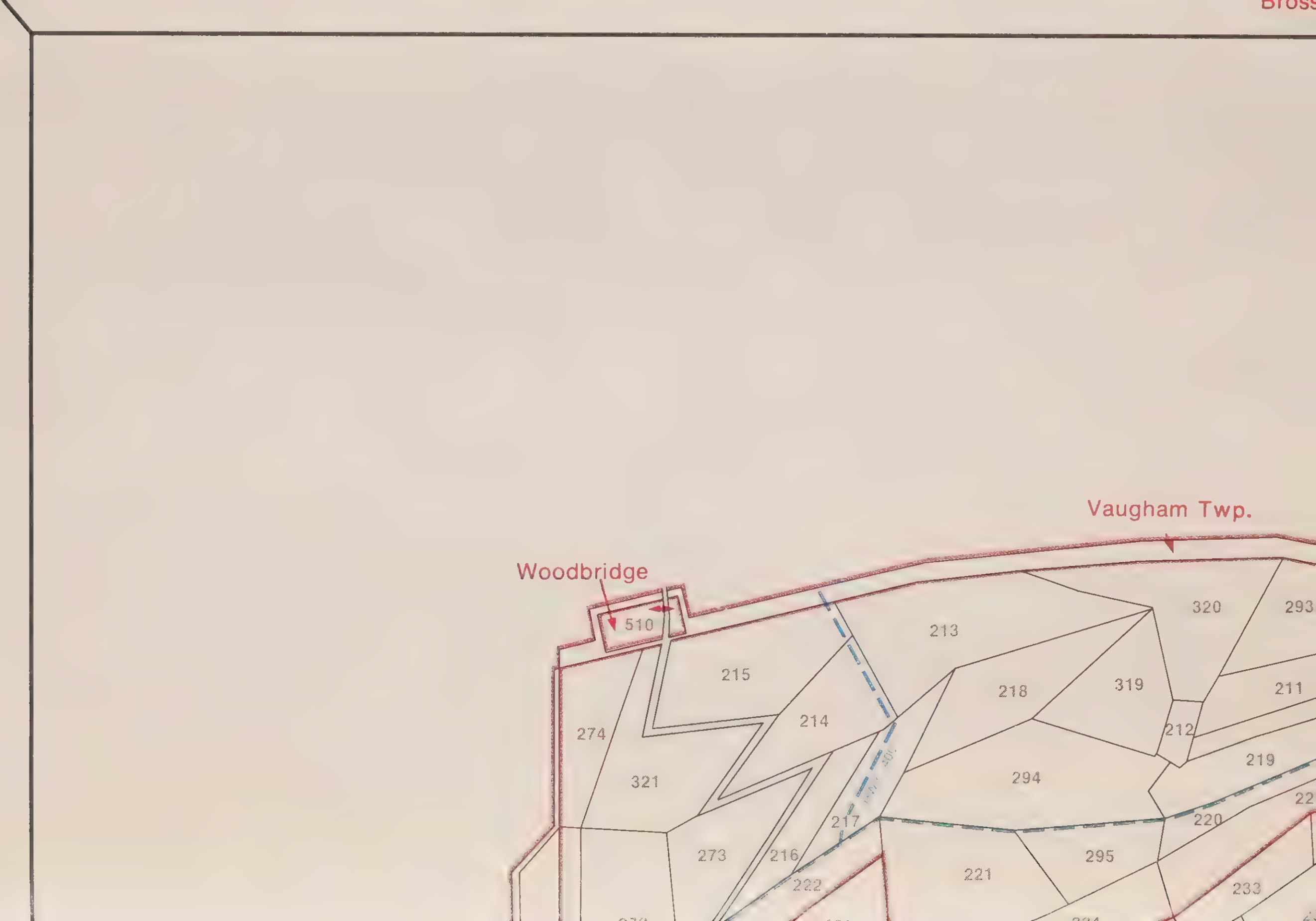
ISODEMOGRAPHIC MAP OF CANADA




Woodbridge
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Canada Dept. of the Environment Lands Directorate

ISODEMOGRAPHIC MAPS OF MAJOR CITIES

AREA

ÉCHELLE DE

45 Census Division Boundary

(C.M.A.) Census Metropolitan Area

(C.M.U.A.) Selected Census Major Urban Areas

(City) Selected Incorporated City

International Boundary

Provincial Boundary

River (Schematic only, river has no isodemographic area)

Note:

Census Divisions form the primary reference on this map. Their boundaries enc
to their population. The position of all other line detail is approximate when not
Division Boundaries.

Map prepared by the School of Community and Regional Planning, University o
the Department of Fisheries and Forestry, Ottawa.

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